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LARGE BILATERAL REDUCTIONS IN SUPERPOWER NUCLEAR WEAPONS

A DISSERTATION

SUBMITTED TO THE DEPARTMENT OF ENGINEERING-ECONOMIC SYSTEMS

AND THE COMMITTEE ON GRADUATE STUDIES

OF STANFORD UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

By

Gregory Samuel Parnell

July 1985

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ABSTRACT

The plausibility and stability of alternative states of the world with large bilateral reductions in nuclear weapons are examined. The current state, with approximately 50,000 nuclear weapons, is compared with two alternative states with arms control agreements with significant verification provisions. The first, minimum deterrence, reduces each superpower's nuclear weapons to a few hundred each and prohibits strategic defense. The second, zero-nuclear-weapons deterrence, abolishes deployed nuclear weapons; but, the superpowers maintain the capability to assemble and deploy a few hundred nuclear weapons on short notice. Strategic defense is encouraged to decrease the incentive to violate the arms control agreements.

A conceptual framework is described that captures the fundamental arms procurement and arms control structure in economic terms, i.e., two governments (nations) fund two monopolists (defense industries) to produce, using essentially the same technology, complementary public goods (weapons) for two sets of consumers (citizens).

The three states are considered the initial conditions and four analyses are performed: potential attack (either a false alarm, an accidental attack, or an intentional attack) stability, major superpower crisis stability, arms procurement stability (the incentives to procure weapons which, although not in violation of the arms control

agreements, may be destabilizing), and arms control stability (the incentives to violate the agreements).

The analysis focuses on arms procurement and arms control stability. The conceptual framework is expanded into a deterministic microeconomic model, and the alternatives are compared using cooperative and noncooperative static equilibrium concepts, e.g. collusion, Stackelberg (leader/follower), and Cournot-Nash. Next, the other country's arms procurement and arms violation decisions are considered random variables, and the effects of uncertainty and information are analyzed.

The ~~dissertation~~ results provide insight into strategic behavior in the current and the two alternative states. First, the current and the zero-nuclear-weapons states are generally more stable than minimum deterrence. Second, the effects of uncertainty on procurement decision-making are relatively minor, and, therefore, the value of information is not large. Third, the strategic defense assumption for each state is very important. Strategic defense creates an incentive to violate the agreements in the current and minimum deterrence states, and the stability of the zero-nuclear-weapons alternative is based on the assumed effectiveness of strategic defense. Finally, if the U.S. is the follower, the leader/follower approach results in the least incentive to procure.

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1. INTRODUCTION

Forty years after the introduction of nuclear weapons it is instructive to reflect on Albert Einstein's famous comment on the impact of nuclear weapons: "the unleashed power of the atom has changed everything save our modes of thinking and we thus drift toward unparalleled catastrophe." In a very fundamental sense our modes of thinking have in fact changed; we accept nuclear weapons and mutual assured destruction (MAD) as unavoidable and, according to the majority of strategic analysts and politicians, even desirable. It is indeed ironic that the general consensus on the potential for "unparalleled catastrophe" has been used to justify the current high levels of nuclear weapons and the acceptance of MAD.

The nuclear weapons revolution has dramatically affected our view of the past forty years, the present, and the future. Many analysts and politicians accept the unprovable hypothesis that the unprecedented destructiveness of nuclear weapons has prevented a third world war. Currently, notwithstanding the loud protests of the peace movements, there is not a consensus that the world is "drifting" toward a nuclear war, but rather general agreement that the current state of the world, with very high levels of nuclear weapons, is surprisingly stable although continually in need of preventive maintenance. Finally, there is a consensus that the transition to alternative states of the world with significantly less nuclear weapons is virtually impossible in the foreseeable future.

I believe the above analysis misses the central question: are there alternative states of the world with significant reductions in nuclear weapons that would improve world security without retaining the Damocle's sword of unparalleled catastrophe? This is the central research question of this dissertation.

1.1 Background

During World War II, many prominent scientists, military leaders and political leaders concluded that it was possible to develop a weapon of unprecedented destructive power by controlling the energy released by nuclear fission. Major research and development efforts began in Germany, the United States and the Soviet Union. The highly classified United States effort, code named the Manhattan Project, included the British but not the other allies. Even though the U.S. was allied with the Soviet Union, President Roosevelt intentionally did not tell Stalin about the Manhattan project.

The initial American motivation was to develop nuclear weapons before the Germans could develop the weapons and use them against the Allies. Later, when it became apparent that the Allies would defeat Germany and their European allies before the nuclear bomb was available, the U.S. leadership began to consider the use of nuclear weapons against Japan to avoid a prolonged invasion with the likelihood of large American casualties. The only two nuclear weapons used during a war were exploded over Hiroshima and Nagasaki. By today's nuclear technology standards these atom bombs were very small. The first atom bomb, a 14 kt (a kiloton, or kt, is the equivalent of 1,000 tons of TNT) fission bomb, was dropped on Hiroshima on 6 August 1945 and resulted in approximately 66,000 deaths almost immediately and 69,000 subsequent injuries out of a population of 255,000. Three days later a 20 kt atom bomb was exploded over Nagasaki and resulted in approximately 39,000 fatalities and 25,000 injuries out of a population of 195,000.

Nuclear weapons were one of three major technologies introduced in World War II that were to play a more critical role after the war. The second major technological innovation was the long range delivery systems used for these nuclear weapons, i.e. strategic bombers. Even armed with conventional weapons, the strategic bomber proved to be capable of vast destruction of industrial and population centers, as the firestorms started in Tokyo and Dresden demonstrated. For example, the fire-bombing of Dresden killed approximately 50,000 civilians. A third important new technology introduced in World War II was the German V-2 which, with a payload of 1 ton of chemical explosives and a range of 200 miles, was the world's first ballistic missile and the harbinger of the intercontinental ballistic missile (ICBM).

Bernard Brodie's oft quoted assessment of the impact of nuclear weapons was that two major characteristics of nuclear weapons overshadowed everthing else: their existence and their incredible destructiveness. However, six further developments greatly complicated the postwar predicament. The first was the development of the thermonuclear (also referred to as fusion or hydrogen) bomb, tested by the U.S. in 1952 with a yield of 1 Mt (a Mt, or megaton, is the equivalent of 1,000,000 tons of TNT), which was significantly more destructive than the previous fission bombs. The largest hydrogen weapon was the 50-60 Mt bomb tested by the Soviet Union in 1961. For comparison, the total bombs used in six years of World War II are estimated to have been approximately 6 Mt and resulted in approximately 50 million deaths. The second factor was the tremendous increase in the number of nuclear weapons up to a level of approximately 50,000 weapons. The third factor was the development of the ICBM which permitted the delivery of nuclear weapons over intercontinental ranges in approximately 30 minutes. The fourth development was the many improvements in technologies and the new nuclear weapon delivery systems, e.g., SLBM, MIRV, accuracy improvements, cruise missiles, and electronics miniaturization. The fifth development was the proliferation of nuclear weapons to other countries. The Soviet Union exploded its first atom bomb in 1949 and its first fusion bomb in 1953. Other countries followed shortly thereafter: Great Britain in 1952, France in 1960, and China in 1964. The sixth factor was the inability of defense establishments to develop effective defenses against nuclear weapon systems. However, in the postwar period, research and development (R&D) continued on defensive systems with varying degree of emphasis, and some limited antiballistic missile (ABM) systems were deployed, e.g., the current Soviet ABM system around Moscow.

Although there have been no further wartime uses of nuclear weapons, the testing of nuclear weapons has continued in the postwar period. After the first aboveground nuclear explosions over Alamagordo, Hiroshima, and Nagasaki, nuclear weapons were tested closer to the ground and the result was an unpredicted and hazardous fallout of radioactive debris. The public outcry about the effects of fallout eventually resulted in the negotiation by the U.S., the Soviet Union, and Great Britain of the Limited Test Ban Treaty of 1963 that banned testing of nuclear weapons in the atmosphere, outer space, and under water. There have been approximately 1440 nuclear tests since 1945; but, since this treaty, almost all the nuclear testing has been done underground. In 1983 there were approximately 50 underground tests (SIPRI 1984).

Nuclear testing has been required to support the development of new nuclear weapons and the reliability testing of existing nuclear weapons. Currently there are approximately 50,000 nuclear weapons with a total megatonnage estimated to be 13,000 Mt. Together the superpowers have approximately 97 % of the nuclear weapons and 98 % of the megatonnage (IISS 1985).

As these vast nuclear weapons systems were developed and deployed, nuclear strategies were developed to integrate them into national security policies. The dominant American nuclear strategy has been deterrence. The fundamental tenet of deterrence is that the U.S. deters the Soviet Union from a nuclear attack on the United States by maintaining a survivable nuclear retaliatory force capable of doing unacceptable damage to the Soviet Union. The concept of extended deterrence includes the major U.S. allies under the deterrence umbrella and relies on strategic and theater nuclear weapons to offset the Soviet Union's European conventional force superiority. Therefore, nuclear weapons are used to deter the Soviet Union from either a conventional or a nuclear attack on Western Europe.

In the past five years, there has been increased concern about the long term effects of a nuclear war on the planet and the human species. The focus of this recent interest is on the possible phenomenon of nuclear winter (e.g., NRC 1985). Nuclear winter refers to the potential significant temperature reductions over the earth subsequent to a nuclear war due to the soot and smoke that would rise into the atmosphere and block the penetration of the sun's rays to the surface of the earth. To estimate the atmospheric effects of a nuclear war, assumptions must be made about the types and quantities of nuclear weapons used in the nuclear exchange. Large uncertainties exist about the initial effects of these weapons, i.e., the initial conditions, and about the sophisticated computer models used to analyze the dynamic effects that would follow. However, many distinguished scientists view the extinction of the human species as a possible outcome of the large scale use of nuclear weapons by one or both of the superpowers.

1.2 Scope

There is general agreement in the arms control literature on the three major objectives of nuclear arms control. The first objective is to reduce the probability of nuclear war. The second objective is to reduce the destructiveness of a nuclear war should it occur. The third objective is to reduce the costs of defense. However, there is no agreement on the priority of these objectives. Many strategic analysts and political leaders have argued that the first two of the above objectives are so important that they should take priority over the issue of defense costs. Others, for example Brodie (1976), have argued that arms control can do very little to achieve the first two objectives and, therefore, arms control efforts should concentrate on the more modest goal of reduced defense spending.

Most of the past nuclear arms control agreements have involved primarily the first and the third arms control objectives. They have focused on avoiding the deployments of destabilizing nuclear weapon systems and limiting the growth of future nuclear weapon systems to control defense spending. In this dissertation, we intentionally focus on the second objective of arms control; we design nuclear arms procurement and arms control states of the world with significant reductions in strategic and theater nuclear weapons. Subsequently, we evaluate these alternative states of the world versus the first and the third arms control objectives, but emphasize the analysis of the risk of nuclear war.

To limit our research scope, we have made the following assumptions. First, we assume the superpowers are motivated to cooperate to significantly reduce the levels of nuclear weapons. This could result from a progressive improvement in Soviet/American relations or after a significant nuclear disaster, or near disaster. Jervis (1982, p. 378) noted that "the strongest possible evidence - an all-out war - would render the project irrelevant. Perhaps a regime could be formed only in the wake of a limited nuclear exchange or the accidental firing of a weapon." Second, much of the literature on alternative states of the world assumes a world government or at least an international military force; however, to make our alternatives more plausible, we severely limit our alternative states of the world by retaining the current nation-state system. Third, we are concerned with the plausibility and the stability of these alternative states of the world and we do not address transition strategies, i.e., how we could get from the current state of the world to alternative states of the world, since we believe that transition strategies have little meaning without a plausible and stable end objective.

Fourth, we are concerned with the nuclear superpowers since they hold the vast majority of the nuclear weapons in today's world. We realize that other countries are important, especially at reduced levels of nuclear weapons, but we focus primarily on the superpowers and clearly state our assumptions about the other countries in each state of the world. Finally, for plausibility reasons, we limit our scope to nuclear weapons reductions versus general and complete disarmament of all nuclear and conventional forces.

1.3 Objectives

There are three objectives of this dissertation research. The first objective is to improve insight into the current U.S./U.S.S.R. arms procurement and arms control system (i.e. state of the world) by providing a better understanding of the fundamental structure and incentives that influence and constrain internal decision-making and strategic interaction. The second objective is to design plausible and stable alternative states of the world with significantly lower numbers of nuclear weapons. The final objective is to analyze the mutual security provided the superpowers by these alternative states of the world.

1.4 Overview

In Chapter 2, we describe the current nuclear arms procurement and arms control state of the world and identify a conceptual framework for analysis of the current and alternative states of the world. In Chapter 3, the designs of the two alternative states of the world are developed. In Chapter 4, we consider potential attack and superpower crisis stability. In Chapter 5, we analyze arms procurement and control stability; we expand our conceptual framework into a static deterministic model and examine the incentives to procure weapons and the incentives to violate the arms control agreements in the current and alternative states of the world, assuming cooperative and noncooperative decision-making. Next, we analyze the effects of uncertainty and the value of information. Finally, in Chapter 6, we summarize the results and the conclusions of the research.

1.5 Model Limitations and Validation

This research involves the design of possible, but not necessarily probable, alternative futures with significant reductions in the levels of nuclear weapons. Since the introduction of nuclear weapons in 1945, the quantities of nuclear weapons have increased; therefore, there is little or no historical basis to enable the use of inductive reasoning and our research strategy must rely on deductive reasoning. In addition, our modeling approach for analyzing superpower arms procurement and control incentives has several important limitations. First, we assume the unitary actor model of nations, i.e., that each nation can be modeled as a single actor. Second, we assume the existence of national value functions and the rationality of the national decision-makers. Specifically, we assume that each nation's value function has two component's: the value of the defense industry and the value of the nation less the defense industry. Third, since our research objectives do not include detailed war planning or analysis of alternative weapon systems, we assume we can reduce the weapon systems to a small number of defense public good categories. Specifically, we assume credible functions exist for each state of the world that map weapon systems into three defense public goods: nuclear weapons, strategic defense, and conventional forces. Finally, the model is extremely difficult, if not impossible, to validate. Therefore, the "validation" of our model must rely on its ability to reasonably describe superpower incentives in the current state of the world and in the period leading up to the present.

1.6 Major Research Contributions

I believe this dissertation provides four major research contributions. First, it provides a conceptual framework that captures the fundamental structure of the superpowers' nuclear arms procurement and control decision-making. In economic terms, the underlying structure is two governments (nations) each funding a monopolist (defense industry), with basically the same technology, to provide complementary public goods (weapons) to two different sets of consumers (citizens). Second, the research provides a detailed political-military description and design of alternative states of the world with significant reductions in nuclear weapons. Third, it defines four important types of analyses necessary to assess the plausibility and stability of alternative states: potential attack decision-making, superpower crisis decision-making, arms procurement incentives, and incentives to violate the arms control agreements. Fourth, the research expands the conceptual framework into a microeconomic model and applies existing microeconomic static equilibrium analysis and decision analysis techniques to answer interesting questions about arms procurement and arms violation incentives in the alternative states of the world.

1.7 Summary of Results.

The major dissertation results are summarized in this section. We describe the general results that do not depend on the state of the world and summarize the major conclusions about each of the three states of the world. In both cases, the results come from the qualitative research and the modeling research performed in this dissertation. Of course, the results of the modeling research are based on the assumptions made in our model formulation.

The major result of our analysis of the current arms procurement and control state of the world (state 1) is the identification and description of four major interrelated factors: the superpowers' international competition, the nuclear security dilemma, technology, and the defense industries. We also describe a conceptual framework that includes the last three factors and is the basis for our modeling and analysis.

Our conclusion from the literature survey is that neither nuclear arms control nor nuclear disarmament advocates have identified or adequately defined the political-military characteristics of alternative states of the world with significant reductions in nuclear weapons. Therefore, we design alternative states with significant reductions in nuclear weapons, minimum deterrence (state 2) and zero-nuclear-weapons deterrence (state 3), focusing on the important political-military features. We also identify the major design issues that affect the plausibility or stability of the state.

We operationalize our concept of stability by defining and analyzing the following four essential types of stability analyses: potential attack, superpower crisis, arms procurement, and arms control agreement violations. To focus on the different decisions in each state, we use influence diagrams to examine potential attack and crisis stability; as expected, the survivability of the nuclear forces/capability is a critical design paramenter.

We expand our conceptual framework into a microeconomic model and analyze arms procurement and control stability, assuming cooperative and noncooperative decision-making. There are five general results from this analysis. First, the decision-maker's relative values (i.e., the relative value of expected destruction versus decreased procurement budget expenditures and the relative value assigned the defense industry versus the nation less the defense industry) are very important in determining arms procurement and control decisions. Second, cooperative decision-making results in a lower incentive to procure defense products;

depending on the decision-maker's relative values, the cooperative decision-making solution is not to procure or to procure strategic defense. Third, the SALT approach of equal future controlled nuclear weapons is never optimal for either cooperative or noncooperative decision-making in states 1 or 2. Fourth, the strategic defense assumption is critical in all states of the world. Without strategic defense, the decision-makers never prefer to violate the agreement; however, with effective strategic defense there is an incentive to violate the arms control agreements in states 1 and 2. Fifth, uncertainty and information are only important for a surprisingly limited range of relative values; however, uncertainty and information are more important in states 1 and 2 with effective strategic defense.

The first alternative evaluated in our research is the current state. The current noncomprehensive arms control agreements are plausible results of this state and the superpower's subsequent actions are consistent with the incentive structures resulting from these arms control agreements. As expected, the high nuclear weapons levels significantly reduce the effects of uncertainty and, therefore, the value of information. Without effective strategic defense, the decision-makers never prefer to violate the arms control agreement since they can procure nuclear weapons that do not violate the arms control agreements. The current state may be more crisis stable, since the potential damage, should war occur, may deter the start of any conflict. The current state is the most arms procurement stable, i.e., both countries have large incentives to procure weapons that do not violate the arms control agreements; however, if effective strategic defense is available, they may prefer to violate the agreements.

The second alternative examined in this research is minimum deterrence. The superpower geopolitical asymmetries complicate the determination of the minimum deterrence levels of nuclear weapons. The evaluation of minimum deterrence is less favorable by most stability criteria; minimum deterrence is less arms procurement and arms control stable and is the most affected by uncertainty. However, the probability of accidental war is lower than our current state of the world due to the reduced number of independent nuclear actors.

The third alternative is zero-nuclear-weapons deterrence. Clearly this state would be the most difficult to achieve; the large numbers of nuclear weapons guarantee the Soviet Union superpower status by offsetting difficult geopolitical challenges from bordering countries and economic inferiority compared to Western economies. The following results assume the availabilty of effective strategic defenses. Without arms control violations, the probability of an accidental nuclear weapon usage is zero since, without arms control agreement violations, there are no deployed nuclear weapons that could be accidentally launched. If there were violations, the strategic defense capability would be successful against an accidental missile launch. State 3 is the most arms control stable since strategic defense reduces the incentive to violate the arms control agreements. With strategic defense, the effects of uncertainty and the value of information are minimal. However, without strategic defense, the zero-nuclear-weapon state would be less stable than minimum deterrence.

Transition strategies were not in the scope of this research; however, our analysis suggests important problems for transition strategy research. First, transition states with low levels of nuclear weapons are less stable than the current state and the zero-nuclear-weapon state. Second, conclusions about transition strategies will be very sensitive to the assumptions made about strategic defense since effective strategic defense creates an incentive to violate arms control agreements that prohibit strategic defense.

Finally, this research identifies an interesting approach to nuclear arms control. We found that a properly designed leader-follower approach (i.e., a nuclear arms control regime in which the follower country agrees to procure the same weapons as the leader country) provides the lowest incentive to procure nuclear weapons or violate the arms control agreements, if the leader has the smaller defense capability and poorer technology. In this arms control regime, if the leader procures, the follower will procure the same amount of higher technology weapons;

therefore, the leader's incentive to procure weapons is reduced. However, if the leader has the larger defense capability and better technology, the leader has a larger incentive to procure nuclear weapons to maintain, or improve, its relative advantage over the other superpower.

2. CURRENT STATE OF THE WORLD

In the previous chapter, we briefly summarized the early nuclear weapons developments and the major nuclear arms procurement and arms control developments since 1945. Next, we attempt to capture the fundamental structure of the very complex process of nuclear arms procurement and control. Keeping our research objective in mind, we highlite only the essential features necessary to understand the current arms procurement and control state of the world and to evaluate our alternative states. We describe the current nuclear arms procurement and control state of the world and propose a conceptual framework for analyzing the current and alternative states of the world in which the nation-state system is retained and the superpowers continue to be the dominant nuclear powers.

First, we identify and describe the four major interrelated factors that affect nuclear arms procurement and control decisions. Second, we examine the organizational incentives that result from the interaction of these four factors and argue that the weapon systems that have in fact been developed and the arms control agreements that have in fact been negotiated are plausible results of this incentive structure. Third, we generalize this incentive structure to a conceptual framework for analyzing alternative states of the world with major reductions in superpower nuclear weapons.

2.1 Description

Our description of the superpowers' decision-making and strategic interaction in the current nuclear arms procurement and control state of the world is organized into four important, interrelated factors: the superpowers' international competition, the superpower nuclear security dilemma, technology, and the defense industries.

Superpower International Competition

The superpowers' international competition is the result of significant conflicts underlying the Soviet/American relationship; we describe four major elements of the competition. First, we identify the fundamental ideological differences and mutual distrust that form the foundation of the competition. Second, we describe the different geopolitical circumstances confronting the superpowers and the resulting similar alliance systems. Third, we compare the economic capabilities of the superpowers. Finally, we contrast the superpowers' conflicting policy goals towards allies and the third world.

The insecure foundation of the Soviet/American relationship results from fundamental ideological differences (socialism, communism, and agnosticism versus democracy, capitalism, and Christianity) and a history of mutual distrust and conflict dating from the Russian Revolution of 1917. The only major period of cooperation since the formation of the Soviet Union was forced upon them by common enemies in World War II. Even this cooperation waned as it became apparent that the Allies would defeat

Germany and Japan and both countries began to posture to strengthen their positions in the postwar era. This fundamental distrust is evident in the current state of the world in such rhetorical questions as the following: how can we deal with a nation that would show no remorse after shooting down a civilian airliner (KAL 007), and how can we trust the Soviets to comply with new agreements when they have always violated previous arms control agreements?

A second feature of the relationship is that, in spite of different geopolitical circumstances, both superpowers have met their national security challenges by forming a major alliance with European allies. The Soviet Union's geopolitical requirements result from its location in Eurasia surrounded by several potential enemies; in contrast, the U.S. is geographically isolated from Europe, and its neighbors are not major threatening powers. To offset the geopolitical differences and the threat posed by the other superpower to itself and its major allies, both superpowers maintain unprecedented peacetime military, political, and economic alliances.

The third factor in the international competition is the superpower economic asymmetry. The International Institute for Strategic Studies estimates that the Soviet Union's 1982 gross national product (GNP) was $ 1,350-1600 billion versus the 1982 U.S. GNP of $ 3,500 billion. If these figures are accurate, the Soviet GNP is approximately 40-45 % of the American GNP.

The final factor in the relationship is the conflicting national policy goals concerning allies and the third world. The national policies have been labeled in the West as Soviet expanionism and American containment. Regardless of the validity of these labels, the third world continues to be the focus of superpower competition and potential conflict. Both superpowers attempt to expand their influence, and limit the opponents' influence, with allies and third world countries, by supporting friendly governments or friendly factions outside of the ruling elite.

This international competition directly impacts the current arms procurement and control state of the world. The nuclear arms control process is profoundly affected by the status of Soviet/American relations; but, the causality should be clearly understood. The history of superpower nuclear arms control shows that a byproduct of a period of relatively reduced conflict and increased cooperation may be arms control agreements and not that arms control agreements result in good relations, e.g., SALT II. In addition, the nuclear arms procurement process is also affected by the competition. Many nuclear weapon system procurement decisions, especially in the United States, have been initiated during periods of tense Soviet/American relations, e.g., Pershing II and GLCMs.

Nuclear Security Dilemma

The complexity of the superpower international competition is greatly increased by the nuclear security dilemma. Each superpower's national security is coupled to the others; an action superpower A takes to increase its national security, such as a weapons procurement, may decrease superpower B's national security and provide country B incentives for similar, or compensating actions, to counter A's actions. The security dilemma is that, while each superpower has strong incentives to unilaterally act to increase its own national security, the net effect of the actions of both superpowers may be a decrease in the national security of both countries. This dilemma is especially perverse for nuclear weapons and is characterized in our current state of the world by the following: the nuclear weapons parity, the asymmetry in nuclear forces, the European conventional force imbalance, the asymmetry of nuclear allies, the different nuclear strategies, and the information asymmetry.

Many strategic analysts believe that the Soviet attainment of nuclear parity in the early 1970s was a necessary condition for serious arms control negotiations between the superpowers; however, even with parity in total nuclear weapons, the U.S. and the Soviet Union have significantly different force structures. The U.S. has emphasized smaller strategic missiles and a balanced triad of strategic forces; the Soviets have developed much larger missiles and have placed more relative emphasis on ICBM programs. These disparate strategic force structures are due to differences in availability of technologies, geomilitary requirements, and leadership preferences.

The next two factors are especially critical in the European balance. Since World War II, there has been a major imbalance of conventional forces on alert in Europe in favor of the Soviet Union. NATO relies on the potential use of nuclear weapons to deter a conventional attack by the Warsaw Pact. Also, there is a nuclear allies asymmetry in favor of the U.S.; two major U.S. allies, Great Britain and France, have developed and deployed nuclear weapons while none of the Soviet's European allies have independent nuclear capabilities.

Many strategic analysts have emphasized the importance of the asymmetry in superpower nuclear strategies. The U.S. declaratory policy has generally been a form of mutual deterrence based on the offense dominance of nuclear weapons. The Soviet concept, although there is no Russian word equivalent to deterrence, is generally referred to as deterrence by denial, which attempts to deter by denying the opponent the the ability to win a nuclear war. The superpowers have not maintained consistent policies on the role of strategic defense. In the postwar period, the Soviets have placed more emphasis on strategic defense than the U.S.; however, by agreeing to the ABM Treaty, the Soviets implicitly accepted the fundamental tenets of mutual deterrence. The President's Strategic Defense Initiative, while at this stage only a research and development program, and the Reagan Administration's public negotiating position in the current Soviet/American umbrella arms control talks portend an attempt to shift U.S. strategic policy away from offense dominance.

The nuclear security dilemma is compounded by the superpowers' information asymmetry. The U.S. is an open society; but, the Soviet Union attempts to maintain a closed society and to control all forms of information. As a result, information about American national security policies, nuclear weapon systems, and arms control negotiation positions is much more available than comparable information in the Soviet Union. This information asymmetry provides an important Soviet arms control negotiation advantage.

The nuclear security dilemma has a major impact on the current arms procurement and control state of the world. The asymmetries in the nuclear forces, conventional forces, nuclear allies, nuclear strategies and information have greatly complicated the nuclear arms control negotiations. Furthermore, these factors (other than the nuclear allies asymmetry) have also been used to justify nuclear arms procurement decisions. Finally, the NATO coupling of nuclear forces to the conventional forces imbalance in Europe makes it difficult to assess nuclear forces separate from conventional forces.

Technology

The superpower leaders attempt to use technology to improve their states' relative positions in the nuclear security dilemma. The technologies of nuclear weapons, nuclear weapon delivery systems, and defensive systems play a critical role in the current arms procurement and control state of the world. The following four aspects of technology are described in this section: the opportunities and contraints technology provides to decision-makers, the superpower technology asymmetry in favor of the U.S., the long lead time for the development of weapon systems, and the role of technology in the verification of arms control agreements.

Technology provides attractive unilateral opportunities and difficult constraints for superpower decision-makers. In the past, fusion, MIRVs, and improved ICBM accuracy have been irrestible technologies. Major examples of technological opportunities currently under development include cruise missiles and improved SLBM accuracy. The fundamental reality in the nuclear era has been offense dominance. During the postwar period, defense against nuclear weapons was initially judged infeasible; subsequently, defense has been assessed as potentially feasible but probably not cost effective (in the sense that any defensive move can be countered by an offensive move at lower cost) and, therefore, destabilizing. The Strategic Defense Initiative is a major long range attempt to alter this constraint by developing technology to reduce the offense dominance of nuclear weapons.

The laws of science are the same for both superpowers; however, the U.S. generally attains an advanced technology a few years before the Soviet Union. According to the

Department of Defense's 1983 basic technology assessment, the U.S. leads the Soviet Union in 15 of 20 technologies deemed most appropriate to military applications. This technological asymmetry is considered a major American national security strength. In reality, this technology asymmetry is best thought of as a time delay since the Soviet Union usually eventually obtains a comparable technical capability.

A third technology factor is the long lead time, 10-15 years, from inception of a weapon system concept to deployment of the weapon system. This long lead time, combined with the fear of falling behind the opponent in some weapon system, encourages decision-makers to make early program commitments to a potential weapon system long before the opponent's future weapon systems can be confidently predicted.

The final important technology aspect is the role of technology in the verification of nuclear arms control agreements. Currently, arms control agreement verification relies heavily on national technical means (NTM), e.g., satellite reconnaissance, versus more intrusive on-site inspection; therefore, arms control agreements have been structured to control weapon system features that can be verified by NTM. As we will see in Section 2.2, this verification constraint has had a major impact on the arms procurement incentives of the superpowers.

Defense Industries

The purveyors of nuclear weapons technology are the defense industries of each superpower. One of the most important symmetries in the Soviet/American relationship is the prominant role played by the military industrial complexes in the domestic organization of each superpower. For example, for FY85 aproximately 64 % of the U.S. federal employees work on defense activities and defense spending comprises 27 % of the federal budget. While credible numbers are not known for the Soviet Union, most experts believe that the number of defense workers is larger, and the defense spending is a higher percentage of the budget. In both countries, the defense industries are very large and maintain their product lines for extended periods.

One difference in the respective military industrial complexes is that, while in the U.S. defense industries are largely private firms, in the Soviet Union they are all public organizations. However, while the defense industry in neither country is organizationally subordinate to the defense department, both defense departments exert considerable de facto control over their respective defense industries through control of program budget, weapon system designs, and product acceptance.

2.2 Arms Procurement and Control Incentives

To better understand the interrelationships of the above four major factors, we next analyze the resulting arms procurement and arms control incentives by considering two categories. The first category includes groups with major vested interests in nuclear weapon systems and is composed of the other major nuclear states; minor nuclear and nuclear-capable states; the government defense establishments; and the defense industries. The second category is the complement of the first category and includes all other countries, the government non-defense establishments, and the non-defense industries. The second category is included since its incentives become more relevant, e.g., the non-nuclear states, in the alternative states of the world with significantly reduced quantities of nuclear weapons.

<u>Other Major Nuclear States</u>

The superpowers procure and maintain the vast majority of today's nuclear weapons at significant opportunity cost to their respective societies. The other major nuclear states (i.e., Great Britain, France, and China) maintain minimum deterrence nuclear weapon forces. Although they periodically modernize their nuclear forces, they have few incentives to significantly increase the number of nuclear weapons because of alliances with the superpowers and the political and economic impacts such a change would have on their countries.

<u>Minor Nuclear and Nuclear-Capable States</u>

There are two potential incentives for countries in this group to obtain nuclear weapons in today's world. The first is to enhance their national security against potential threats from neighboring countries, e.g., Israel.

The second is to perform terrorist actions against neighbor states or the superpowers. It is important to note that nuclear proliferation has not been the problem some politicians and analysts predicted in the 1960s. It is generally believed that four minor nuclear states have nuclear weapons and another four countries are seeking the capability.

Superpower Government Defense Establishments

Each superpower's government defense establishment has a strong vested interest in nuclear weapon systems and has complex arms procurement and control incentives. Our analysis is organized into three areas. First, we examine the defense establishment's incentives to procure arms. Second, we discuss the incentives to support the negotiation of limited arms control objectives. Third, we focus on the incentives to couple arms control support to arms procurement approval.

The defense establishment has several incentives to continue nuclear weapon system research, development and procurement. First, a technology lead can be used to maintain national security by applying new technologies to future weapon systems. Second, there are incentives to perform research to avoid unforeseen technical breakthroughs by the opponent and to hedge against the possibility that the opponent will violate the current arms control agreements. Third, there is an incentive to justify defense expenditures by emphasizing the technological threat from the opponent. The superpower international competition and the information asymmetry can lead to a worst-case analysis of each other's capabilities and intentions. A final bureaucratic incentive is the desire to maintain the prominent position in the government by continuing to employ a majority of the federal employees and a large share of the national budget.

The defense establishment does have incentives to support limited nuclear arms control agreements, provided national security is increased without incurring major risks, to enable the reallocation of defense spending to other areas, e.g., conventional forces. Since the defense establishment does not trust the other superpower and wants early notification of treaty violations, the defense establishment demands verifiable arms control provisions. However, the existing monitoring technology severely limits the nuclear weapon system parameters that can be verified by NTM and the Soviets, to date, have refused most potentially intrusive methods of on-site inspection. Therefore, the nuclear arms control agreements have been noncomprehensive agreements. Of course, on-site inspection would be very difficult to implement and would not provide complete confidence that the other country is complying with the arms control agreements.

If arms control agreements are possible, the defense establishment has incentives to couple its support for arms control agreements to arms procurement approvals. There are many ways arms control and procurement have been coupled. Some members of the defense establishment attempt to justify marginal nuclear weapon systems by noting the systems' potential value as "bargaining chips" in future negotiations. Perhaps more important, the defense establishment's support of a limited arms control agreement is usually predicated on funding of other uncontrolled weapon systems.

Superpower Defense Industries

The defense industry, which includes firms devoted primarily to nuclear weapon systems and firms whose business involves a large percentage of defense work, has major incentives to encourage and support the government defense establishment's requests for increased funding for weapons system research, development, and procurement. In the U.S., the major defense firms are private firms whose existence and profits depend heavily on defense contracts; they have strong financial incentives to insure that a market exists for their products. In the Soviet Union, the defense industries are public organizations; however, their organizational power and influence depend on the continued Soviet demand for nuclear weapon systems, in much the same way that the U.S. industries depend on U.S. demand.

All Other States

The states that currently have no nuclear weapons and are not actively seeking nuclear weapons have no incentives to develop nuclear weapons, other than the two incentives mentioned above for the nuclear-capable states. These incentives could increase in one of these states as a result of major domestic or external political changes.

Non-Defense Establishment & Non-Defense Industries

Defense spending has opportunity costs and, therefore, the government non-defense establishment has incentives to reduce defense spending. However, this may not result in an incentive to reduce spending on nuclear weapon systems since nuclear weapon systems are generally less costly, especially to operate and maintain, than comparable amounts of conventional forces.

Arms Control Agreements

Examination of the major nuclear arms control agreements shows that past arms control agreements are plausible results of the incentive structure described in this chapter. The Limited Test Ban of 1963 banned all nuclear testing except underground testing. Significant concern existed at the time about the potential for verification of underground testing and the defense establishment also argued that underground testing was required for the reliability testing of existing nuclear weapons and the development of future nuclear weapons. The ABM Treaty of 1972 was a recognition of the offense dominance of nuclear weapons, but defense establishment support was conditional on funding of other weapon system improvements, e.g. MIRV. The SALT I Interim Agreement on Offensive Systems of 1972 and the SALT II Treaty of 1979 were complex noncomphrensive agreements based on monitoring the number of launchers and weapon system testing by NTM.

The SALT agreements addressed less than 50 % of the superpowers' nuclear weapons but slightly over 50 % of the megatonnage.

Once an arms control agreement has been reached, the internal national decision-making has been predictable based on the incentive structure of the agreement. For example, let us consider the post-agreement incentives provided by SALT I and II. Since launchers were counted instead of warheads, the incentive was provided to MIRV the missiles. Since launchers were counted at the maximum number of MIRVs tested, an incentive was provided to deploy the maximum number of MIRVs tested. Also, setting a maximum throwweight for the new allowed missile provided an incentive to develop M-X with exactly the maximum allowed throwweight. Finally, another major problem is that the lack of a comprehensive agreement provided incentives for developing technology and weapon systems not prohibited, e.g., intermediate nuclear forces such as the SS-20s, Pershing IIs, and GLCMs.

2.3 Conceptual Framework

We propose a conceptual framework for analyzing the current and alternative states of the world in which the nation-state system remains and the superpowers continue to be the dominant nuclear powers. This framework includes three of the four major factors analyzed in this chapter. The superpower international competition is excluded from this framework because, to achieve the alternative states, we make the critical assumption that superpower relations are significantly improved. However, in our subsequent analysis, in Chapter 4, we relax this assumption and explicitly consider the stability of the alternative states during changes in Soviet/American relations including a major superpower crisis.

Figure 2.1 graphically depicts the basic conceptual framework we use to examine the arms procurement and control incentives. The fundamental structure of the arms procurement and control problem can be described in economic terms as two monopolists (defense industries) providing complementary public goods (national defense capability) to two different consumer (citizen) groups. Since the goods are public goods, the two governments (superpowers) pay the monopolists to provide the defense goods. The national defense capabilities are complementary public goods, since if the defense capability in one country increases, the other country's demand also increases. Both monopolists determine their products based on the technology available to them.

The above conceptual model is symmetric; but, our model could be refined by adding two asymmetries. First, one of the defense industries could be modeled as a private firm and the other one as a public organization. Second, in the short run, the two defense industries could have different technologies and different amounts of budget available.

This relatively simple conceptual framework captures the fundamental structure of the nuclear arms procurement

TWO MONOPOLISTS PROVIDING COMPLEMENTARY PUBLIC GOODS

TO TWO DIFFERENT CONSUMER GROUPS

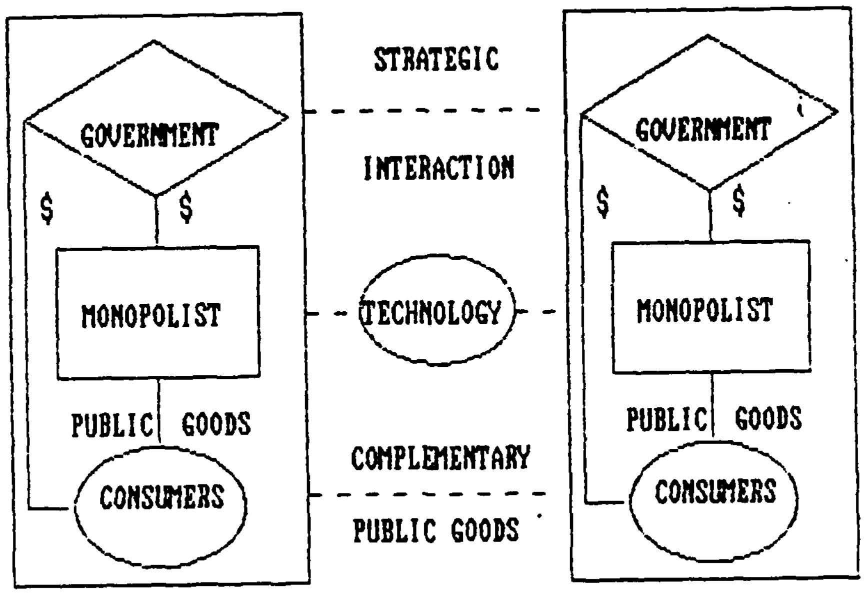


Figure 2.1

and control process. The nuclear security dilemma is similar to the dilemma of complementary public goods. The parallel roles of the governments and the defense industries are accounted for in the framework. Finally, the framework clearly shows how technology couples the superpowers' defense decisions.

This conceptual framework is developed into a more detailed model in Chapter 5. But first, in the next chapter, we describe our conceptualization and design of the alternative states of the world.

3. ALTERNATIVE STATES OF THE WORLD

Currently, mutual deterrence is provided by each superpower maintaining tens of thousands of strategic and theater nuclear weapons and nuclear arms control agreements are limited, noncomprehensive agreements relying primarily on national technical means (NTM) for verification of compliance. Two significantly different states of the world are described: minimum deterrence and zero-nuclear-weapons deterrence. With minimum deterrence, mutual deterrence is provided by each superpower maintaining a few hundreds of nuclear weapons. The arms control agreements are comprehensive and include increased verification provisions including on-site inspection. In the zero-nuclear-weapons state of the world, deployed nuclear weapons are abolished but deterrence is still provided by the capability to deploy a fixed number of nuclear weapons after a built-in time delay. Comprehensive arms control agreements include on-site inspection and strategic defense to decrease the incentives to violate the arms control agreements.

This chapter describes our conceptualization of the alternative states of the world. First, we begin with a brief summary of the literature on alternative states. Second, we identify the major problems complicating the conceptualization of alternative states with significant reductions in nuclear weapons. Third, we describe our approach to the description of the alternative arms procurement and control states of the world. Fourth, we characterize the alternative states we have selected. The subsequent chapters provide a comparative analysis of the current and the alternative states of the world.

3.1 Literature Survey

The literature on alternative arms procurement and arms control states of the world can be separated into two major categories depending on the assumption made about the nation-state system. The first category, which is not within the scope of this research, involves major changes to the nation-state system ranging from an international military force (Schelling 1961 and Gompert et al 1977) to a new world order with a world government. Within the second category, the nation-state system alternatives, the security regime concept is closely related to our design objective. Jervis (1982, p.357) defines a security regime as "those principles, rules, and norms that permit nations to be restrained in their behavior in the belief that others will reciprocate". He identifies four requirements for a security regime: the great powers must want a security regime, each superpower must believe the other values mutual security and cooperation, no state must be expanionist, and war must be seen as very costly.

The next most important organizing theme for the literature involves the scope of the disarmament: general and complete disarmament; complete nuclear disarmament; significant nuclear arms reductions; and other nuclear arms control measures. Schelling (1961) analyzes total disarmament which he defines as similar to the concept of general and complete disarmament; all nuclear and conventional weapons and forces are eliminated except for the internal security forces required for each nation. Other research focuses on complete nuclear disarmament but retains conventional forces and is, therefore, closer to our research scope. Examples of this research are Barton's concept of the proscription of nuclear weapons (Gompert et al 1977) and Schell's (1984) concept of the abolition of nuclear weapons which is the basis of for one of our alternative states.

Other analysts attempt to increase mutual security through a major reduction of nuclear weapons. Szilard (1964) describes a Minimal Deterrent alternative that involves significant reductions in strategic and theater nuclear forces. Szilard uses the mutual assured destruction criteria of 25 million people and calculates a U.S. strategic force of 40 1-3 Mt weapons and a U.S.S.R. strategic force of 12 1-3 Mt weapons (the large difference in force sizes is due to differences in population distributions). The strategic forces wculd be split between SLBMs and ICBMs. He permits each country to maintain an ABM force of 20 kt weapons up to a total of 3 Mts (with no city protection) and theater nuclear forces of 300 1 kt weapons. Others have applied the minimum deterrence idea only to strategic forces due to the conventional force imbalance in Europe and the complexities of controlling theater nuclear forces. For these reasons, Rathjens (1976) rejects complete nuclear disarmament and proposes a 90% reduction in strategic weapons. He considers two alternative strategic force structures: 50 ICBM silos and 6-8 SLBM submarines or 8-12 SLBM submarines. He believes these levels would reduce the risk and consequences of nuclear war. Rathjens' provides the following estimates of the direct fatalites resulting from the use of nuclear weapons in a major war:

		U.S.	U.S.S.R
countervalue:	today	90%	75%
	reduced force	45%	25%
counterforce:	today	5-25 million	
	reduced force	.5-2.5 million	

Other analysts focus their attention on the nuclear weapons in Europe. A wide range of alternatives have been proposed; but, only a few will be discussed here. First, one approach is to remove all nuclear weapons from Europe. This approach is usually predicated on a buildup of conventional forces or a reduction of Soviet conventional forces through arms control agreements. Second, analysts (Freedman 1983) propose eliminating the battlefield nuclear forces but recommend retaining the intermediate nuclear forces (INF). Finally, other analysts recommend more modest proposals, e.g., nuclear-free-zones in Europe and a no-first-use nuclear weapons policy.

Recent studies focus on alternative states of the world (and transition strategies) and illustrate significantly different approaches. An example from the West European peace studies perspective is Galtung (1984). A more wide-ranging collection of articles is the Weston (1984) study in the Just World Order series. Gray (1984) examines the design problem from a nuclear strategy view perspective instead of concentrating on the reduction of nuclear weapons.

3.2 The Design Problem

The current large number of nuclear weapons contribute significantly to the superpower status of both countries, but especially the Soviet Union. Therefore, perhaps the most fundamental obstacle to complete nuclear disarmament is the asymmetry in the geopolitical challenges and economic capabilities of the superpowers. Unlike the U.S., the Soviet Union faces potential enemies on many of its borders. In Section 2.1, we noted that the U.S. GNP is over twice the size of the Soviet GNP. In addition, Jervis (1982, p. 360) notes that superpower decision-makers are not likely to agree to a security regime but rather "usually react by relying on unilateral and competitive modes of behavior rather than seeking cooperative measures". The reasons for these behavior patterns were described in Chapter 2.

However, in our research, we assume that the superpowers want to significantly reduce the numbers of nuclear weapons and then examine the resulting problems. Our objective is to define the major problems for the design of alternative arms procurement and control states of the world with significant reductions in nuclear weapons.

Three authors have made major contributions to the identification of the problems associated with major reductions in nuclear weapons. Jervis (1982) provides the reasons why such a security regime has not been established. Hoeber (1978) analyzes the major problems of low levels of nuclear weapons. Finally, Schelling (1961 and 1966) identifies the major problems with total disarmament.

At least five major design problems exist with large reductions in nuclear weapons. The first design problem is the stability of the alternative states of the world with reduced levels of nuclear weapons. Schelling (1961, p. v) noted that " "total disarmament" does not preclude either war or rearmament. The power and the knowledge to make war,and ... to mobilize and rearm, always exist. There are no strong a priori reasons for supposing that drastic disarmament reduces the advantages that accrue to haste and initiative in war and [rearmament] ... unless it is consciously and selectively designed to do so." The second design problem is that reductions in the destructiveness of war may result in an increase in the likelihood of conventional and/or nuclear war since the threat associated with the initiation of a nuclear war would be diminished. The third major problem is that since nuclear weapons are constrained at low levels, the superpowers have increased incentives for procurement of other weapons, e.g., very accurate nonnuclear systems, chemical, and biological weapons. Fourth, major reductions in nuclear weapons may provide incentives for other nuclear powers to increase their nuclear weapons or other nonnuclear countries to obtain a nuclear capability. Finally, major reductions in nuclear weapons require arms control agreements with significant inspection provisions. Most experts believe that strategic weapons can be adequately verified by NTM but that cruise missile and dual-use theater systems require significant on-site inspection. While admitting that negotiating significant levels of inspection would be very difficult, Szilard (1964, p. 10) made an interesting observation: "I believe that it would be much easier to get the Soviet government to accept far-reaching measures of inspection for the sake of obtaining an objective that makes sense to them than to get them to accept quite limited measures of inspection for the sake of any 'first steps' which would not offer any major direct benefits to Russia."

As Schelling (1961 and 1966) noted, disarmament alternatives, partial or total, must be assessed by examining the military capabilities and incentive structure in the alternative state of the world. In our subsequent analysis of the security regime design problem, we examine the problems of maintaining stable deterrence and stable extended deterrence.

Deterrence

The alternative states of the world must maintain mutual deterrence stability. Four aspects of stability are considered: potential attack stability, crisis stability, arms procurement stability, and arms control agreement violation stability. All of these types of stability are influenced by the superpowers' military capabilities and, in fact, the character of weapons and delivery sytems may be as important as the quantity of the weapons.

The potential attack stability is the stability of the state of the world when notification is received of a potential ballistic missile attack on one superpower. This notification could be caused by an accidental missile launch, an error in the warning system, or an intentional attack. Lower numbers do not inherently reduce the risk of accidental nuclear war. For example, an accidental missile launch would threaten a larger percentage of a smaller nuclear force; therefore, if the forces were perceived to be vulnerable, the threatened country would have more incentive to launch on warning.

The crisis stability of the alternative state of the world is a second important design problem. Major issues arise from the tension between military logic and political-diplomatic logic (George 1984) involving the problems of timing and the role of speed and initiative. Military logic puts a premium on the rapid alerting and mobilization of military forces to reduce the risk of potential agressive military actions by the opponent in a crisis. Political-diplomatic logic recognizes that military actions can be construed as offensive, instead of defensive, and attempts to slow down the crisis and resolve the fundamental conflict of interest. The initiation of war (without rearmament) should not be the most conservative choice available to the superpower decision-makers; the structure of the reduced nuclear forces should not allow a superpower to benefit from a preventive or preemptive conventional and/or nuclear attack. Two conclusions can be stated: first, survivability of the nuclear and conventional forces may be more important than in the current state of the world and, second, the dilemma is eased if defensive/retaliatory actions are as effective as offensive/preemptive actions.

The incentives for arms procurement and arms control agreement violations must be considered. The possiblity of undetected nuclear weapons retained at the beginning of the disarmament agreement and systematic violations after the agreement is implemented can not be excluded. Also, the existence of detailed plans to breakout of the agreement, either to obtain an advantage or to respond to the opponents' violations, are very probable. The alternative state of the world can reduce the incentives to violate the agreements by limiting the benefits that a country can hope to achieve.

The capability to significantly increase the number of nuclear weapons will exist even in a nuclear disarmed world and, therefore, rearmament is an important design problem. The rearmament problem is best addressed by what Schelling (1966) calls "rearmament parity": each country must perceive that there is nothing to be gained by nuclear rearmament since the other country will also rearm. However, each superpower must also perceive that there is nothing to be lost by being the second country to begin nuclear rearmament. Long rearmament times may be better since a headstart provides less percentage advantage to overcome.

The survivability of a country's nuclear capability, i.e., deployed retaliatory forces or delayed capability, is the critical factor in the stability analysis. Vulnerability increases the incentive to go first and puts a premium on preventive or preemption actions. In each state of the world, military planning decisions should be made to avoid potential force vulnerabilities.

Hoeber (1978) identifies several important military planning parameters that would would be important issues at low levels of nuclear weapons. I have grouped these issues into four categories: determination of the low levels, technical surprise, important force characteristics, and nuclear war planning. First, population based minimum deterrence levels would be difficult to establish because the Soviet population is more geographically dispersed and because the Soviets have placed more emphasis on active and passive defenses. The Soviets have major programs in civil defense, air defense, and ballistic missile defense; these programs would be more effective against low nuclear weapons levels since the offense may not have the weapons to suppress or saturate the defense. Of course, defense could be limited but verification would be difficult. The second issue is technological surprise which poses more risk at lower nuclear weapons levels. However, the risk of technological surprise, offensive or defensive, can be ameliorated by continued R&D programs in critical technical areas. The third issue is the characteristics of nuclear forces at low levels. The following characteristics would be important: diversity to complicate the opponent's planning and reduce the risk of technical surprise; hardening to enhance survivability; concealment to increase intelligence cycle times and enhance survivability; reload/recycle capabilities to increase force effectiveness; and C3I to improve conservation of the limited forces. Finally, low levels would have the following impacts on nuclear war planning: population targeting would be encouraged since the number of weapons would not be sufficient to take out the nuclear forces and still threaten the population; nuclear weapons would probably be assigned to strategic targets only; and extended nuclear and conventional war planning would be required.

Extended Derterrence

The extended deterrence problem in Europe is a significant design problem for low levels of nuclear weapons. Theater nuclear weapons are deployed in Europe to offset the conventional force imbalance at a lower economic and political cost than a conventional force buildup. The Europeans believe that any war in Europe, nuclear or conventional, would be a diasaster and, therefore, argue for the continued deployment of nuclear weapons to enhance the credibility of the U.S. commitment (Freedman 1981 and 1983).

Even at the current high nuclear weapons levels the credibility of the U.S. commitment is the critical issue, credibility of the U.S. commitment is the critical issue, especially with the large number of Soviet nuclear forces in Europe. Freedman (1983, p. 99) states that "the dilemma of NATO doctrine is how to make it credible to the potential agressor that a U.S. President would authorise (sic) use of nuclear weapons in circumstances where NATO is being defeated in a conventional war." However, Freedman (1983, p.93) notes that "there was no logical reason why a decision to use nuclear weapons would be any easier for an American President with one type of weapon rather than another, but intuition suggested that somehow a decision that was shaped by the exigencies of a European conflict might more plausibly "go nuclear" than one taken from one step removed."

As we consider alternative states of the world, it is important to recognize that NATO's nuclear strategy is being challenged as inadequate across the political spectrum. Conservative analysts believe we may have insufficient nuclear and conventional forces to deter the Soviet Union. Prominent American analysts believe we should adopt a no-first-use policy and rely on improved conventional forces. European peace groups continue to demonstrate to show their opposition to additional nuclear weapons.

3.3 The Design Approach

The alternative states of the world presented here are radical departures from the current state of the world and we have little or no historical experience to draw on in designing these possible, but not probable, future states of the world. It is very useful to consider Herbert Simon's admonitions on designing and social planning. First he emphasizes the limitations in establishing design goals:

> "The idea of final goals is inconsistent with our limited ability to foretell or determine the future. The real result of our actions is to establish initial conditions for the next succeeding stage of action. What we call 'final' goals are in fact criteria for choosing the initial conditions that we will leave to our successors." (p. 187)

Our approach is to design the alternative states of the world and consider the design to be the 'initial conditions' for our subsequent analysis of plausibility and stability. Simon's second admonition concerns the available design data for social planning:

> "The heart of the data problem for design is not forecasting but constructing alternative scenarios for the future and analyzing their sensitivity to errors in the theory and data." (p. 171)

Following Simon's advice, our objective is not to predict or forecast the future, but rather to design possible alternative states of the world and attempt to include in our analysis the sensitivity to our design assumptions and decisions.

The following paragraphs describe the design assumptions and objectives that apply to both alternative states.

Infrastructure

To enhance the plausibility of the alternative states of the world, two major design assumptions are made in our research. First, we assume that the international order retains the nation-state system. Second, we assume the politics of the Military-Industrial Complexes (MIC) in the domestic order of the superpowers is not fundamentally altered. The defense establishment maintains its influence due to the importance of national defense, the high share of the federal budget, and the large percentage of federal employees.

Beliefs

The extent that superpower leaders share the following three tenets increases their incentives to negotiate alternative states of the world with significant reductions in nuclear weapons. First, the motivation for reductions will increase, if the superpowers' elites believe that the current high levels of nuclear weapons pose a significant risk to each nation and potentially the fate of the earth. Second, the potential for bilateral agreements will increase, if leaders recognize that nuclear weapons have caused each superpower's national security to be inexorably intertwined with the other country's national security and believe that mutual security should be the preeminent security goal. Finally, before change can occur, the leaders must believe there are plausible and stable alternative states of the world which could improve their national security by providing mutual security to both superpowers. This belief does not mean that these alternatives have no risk, but rather that the national security risks are less than or equal to the risks associated with the current state of the world.

Overall Status of Soviet-American Relations

Clearly, the overall status of Soviet-American relations would have to be very good to result in an agreement to seek either alternative state of the world, and these relations would have to be maintained during the transition period. These improved relations would require explicit, or implicit, agreements to limit superpower competition. However, our focus is on the plausibility and stability of these alternative states of the world, assuming that the superpowers reach agreements and complete the transition.

Deterrence

For the purpose of our analysis, we must clearly specify what is being deterred in each state of the world. Both alternative states of the world should be designed to deter each superpower from initiating a nuclear or conventional attack on the other superpower and its major allies. However, the alternative states of the world, like our current state of the world, should not be expected to deter military actions resulting from important asymmetries of interest and military power projection capability, for example, the Soviet invasion of Afghanistan in 1979 or the American invasion of Grenada in 1983.

Superpower Internal Decision-Making

In Chapter 2, we analyzed the complex incentive structure in the current arms procurement and control state of the world. Although the alternatives retain the basic infrastructure, i.e., nation-state system and domestic organizations, there is a revised incentive structure based on the design of each alternative state. The stability of the alternative states is enhanced, if the resulting incentive structures properly guide each superpower's internal arms procurement and arms control agreement violation decision-making; each superpower should have strong incentives to comply with the arms control agreements and not have incentives to violate the agreements.

Superpower Strategic Interaction

The U.S. and the U.S.S.R. will continue to interact in a complex world with conflicting national objectives and interests; therefore, we need to analyze the stability of each alternative state. The alternative state should be robust enough to withstand the pressures of a major superpower crisis once the state of the world has been established. The type of crisis requiring careful analysis is a crisis in which Western Europe perceives itself threatened by a massive Soviet Union conventional attack and does not have the current U.S. nuclear deterrent. Also, the alternative state should not provide incentives for arms races that could undermine the agreement by creating the perception of future unacceptable risks to national security.

The arms control agreements will require considerable discussion and negotiations after they are implemented to discuss areas of concern and resolve problems. Bilateral and multilateral forums must be established to achieve and maintain the alternative state.

Expanded economic, social, and scientific cooperation should also be encouraged since these activities would build on the spirit of mutual trust and cooperation already required to establish the alternative state of the world. In addition, the continued benefits from these cooperative activities would provide incentives for both superpowers to comply with the arms control agreements and, more importantly, to avoid conflicts that, if unresolved, could become major superpower crises.

3.4 Minimum Deterrence

Many prominent world leaders, including recent American Presidents, have expressed their hope for significant reductions in nuclear weapons. For example, President Reagan has stated that the U.S. will "negotiate as long as necessary to reduce the numbers of nuclear weapons to a point where neither side threatens the survival of the other." President Carter once considered the possibility of limiting each superpower to 200-250 strategic nuclear delivery vehicles.

In this section, we describe the minimum deterrence state of the world in sufficient detail to analyze its plausibility and stability using the models we develop in subsequent chapters. Our minimum deterrence concept is derived from the concept defined in the early 1960s by various authors as minimum deterrence, minimal deterrence, or minimum assured destruction. Since our research objective is to analyze alternative states of the world, we do not address the issues associated with the transition from the current state of the world, or intermediate states of the world, to the minimum deterrence state of the world.

The fundamental concept of minimum deterrence is that each superpower maintains nuclear forces minimally sufficient to survive a first strike and inflict unacceptable damage on the other in a retaliatory second strike. Szilard (1964) described the minimum deterrence level as the superpower's nuclear force "level just sufficient to inflict "unacceptable" damage in a counterblow in case of a strategic first strike against their territory" and compared the logic of minimum deterrence to the rationale behind the French and British nuclear forces. Enthoven and Smith (1971, p. 171) describe minimum deterrence as the nuclear force posture such that the "U.S. would always have something left, after absorbing an attack, with which to strike Soviet cities and that, regardless of how little, the Soviets would be unwilling to accept that risk". Minimum deterrence connotates a smaller second strike force than assured destruction. In the 1960s, Secretary of Defense McNamara estimated the assured destruction levels to be 20-25% destruction of the opponent's population and 50% of the opponent's industry, and estimated that 400-500 strategic launchers would be required for assured destruction. Minimum deterrence requires a significant amount of inspection; Szilard (1964, p.10) noted that inspection must provide "assurance that

Russia cannot secretly retain a striking force large enough to be capable of destroying a significant fraction of our minimal striking force".

Two corollaries immediately follow from the minimum deterrence concept. First, strategic defense is destabilizing since it reduces the ability of the second strike force to guarantee unacceptable destruction. Second, arms control agreements that limit nuclear offensive systems, prohibit strategic defense, and provide for adequate verification are required to give each superpower the necessary confidence in its second strike capability.

In the 1960s, the primary motivations for the minimum deterrence concept were the concern with the risk of nuclear war if the nuclear weapons levels of both superpowers continued to increase, the recognition that nuclear weapons served mainly as a deterrent for direct attack on the U.S. or its major allies, and attempts by cost-effectiveness minded defense officials to answer the question "how much is enough ?".

In the remainder of this section, we further describe our minimum deterrence design emphasizing the leadership beliefs, the international and domestic infrastructure, the force structure, and the characteristics of arms control agreements in this state of the world.

<u>Beliefs</u>

With minimum deterrence, the populations of the superpowers' major cities are held as nuclear hostages. To achieve and maintain significantly lower nuclear weapons levels, both superpowers must accept this population targeting strategy. However, the leaders might rationalize this strategy by the belief that the lower nuclear weapons levels, even if all nuclear weapons are targeted on cities, would result in less risk to the survival of the human species than a major use of our current nuclear weapons. (Of course, the loss of life and the impact on the environment depend on the size of the attack and the targeting of the "major use of our current nuclear weapons".)

Infrastructure

The major political-military alliances of the superpowers are retained. Extended deterrence is provided by the deployed American conventional forces, the capability to mobilize additional American conventional forces, and the deployed strategic nuclear forces. However, the strategic nuclear forces of the minimum deterrent force are not designed to provide extended deterrence; therefore, a critical issue is European perceptions of the credibility of extended deterrence based on conventional forces.

The MICs of both superpowers are responsible for three major tasks. First, the strategic nuclear weapons deterrent capability must be maintained. Second, conventional forces must be maintained and credible strategies to mobilize and deploy additional forces to NATO must be developed. Finally, since arms control violations involving theater nuclear forces and strategic defense would be very destabilizing, the other country's compliance with the agreements must be closely monitored.

Force Structure

The minimum deterrence force structures of the superpowers, France, Great Britian and China are composed only of strategic nuclear forces. We assume that all nuclear weapons, strategic and theater, are included in the arms control agreements but that only strategic nuclear weapons are allowed. The British and French strategic nuclear forces and the NATO conventional forces are deployed to deter a Soviet attack in Europe; but, no American or NATO theater nuclear forces are provided for extended deterrence. However, there is no credible way to prevent theater targeting by strategic weapons.

There are five major reasons for the above design decisions. First, it is extremely implausible that France, Great Britian, and China would agree to eliminate all of their nuclear weapons, if the superpowers retained some nuclear weapons; however, they might agree to give up their tactical nuclear weapons, if the superpowers make major nuclear weapons reductions. Second, theater nuclear weapons are the most difficult to verify with NTM or even on-site inspection since their survivability relies on their mobility. Zero is the most verifiable number since any nuclear weapon detected is clearly a violation. Third, many analysts, including this author, believe that theater nuclear weapons have the highest probability of being used in a major superpower crisis. Fourth, determining a minimal number of theater nuclear forces to offset the Soviet conventional forces is extremely difficult military and political problem. Finally, small numbers of theater nuclear weapons could provide incentives for premption in a crisis and, therefore, could be be worse than no nuclear weapons.

Several force structure decisions must be made to determine the minimum deterrence level of strategic nuclear weapons, i.e., the number of nuclear weapons minimally sufficient to deter an attack by the other superpower. The major decisions are the types of strategic weapon systems and the quantities of each system. Since the quantity of nuclear weapons is low in minimum deterrence, the decision-makers will want to select types of weapon systems that have one nuclear weapon per weapon system; single warhead systems cost more but will reduce the opponent's incentive to prempt. Either a total number of weapons, or a criterion for calculating the total number of weapons, must be established. Since minimum deterrence is a cities strategy, two possible criteria are x % or y millions of the opponent's population.

Four factors greatly complicate the determination of equitable minimum deterrence levels. First, the Soviet Union has a larger population; but, the U.S. has a greater population density. Second, since the Soviet Union has devoted more effort to civil defense, major assumptions must be made about the availability and effectiveness of civil defense. Third, the U.S. allies in Europe have nuclear weapons but the Soviet allies do not. Finally, an important issue that has been raised explicitly in the last several years is nuclear winter. If the nuclear winter threshold were confidently known, this information could be an important factor in determining the minimum deterrence levels; but, two arguments are possible. One might argue that the minimum deterrence levels should be under the nuclear winter threshold to avoid destruction of the world. However, in the more perverse logic of deterrence, one might argue that the levels should be far enough above the nuclear winter threshold such that either superpower's second strike would be sufficient to exceed the threshold.

Arms Control Agreements

The minimum deterrence arms control agreements must state the types and numbers of allowed nuclear weapons sytems; prohibit strategic defense and space-based offensive weapons; prohibit conventionally armed strategic weapons; and provide for monitoring of R&D activities. This state of the world requires extensive monitoring of R&D since the development, testing, and deployment of offensive weapons are strictly controlled at agreed levels and strategic defense systems are prohibited.

Conventional force technology could also be restricted. However, since conventional forces are significantly more difficult to control than nuclear weapons due to the variety of conventional weapons and the less stringent design and manufacturing requirements, the plausibility of minimum deterrence is enhanced if we minimize the control of conventional weapons. Two conventional force capabilities would be especially destabilizing in the alternative states of the world: space-based systems armed with conventional weapons and, with the accuracy improvements of strategic weapons, conventionally armed strategic systems. Therefore, our concept of minimum deterrence includes the control of space-based conventional weapons and strategic systems with conventional warheads.

Summary

To be plausible and stable, the minimum deterrence state of the world must result in a low probability that either superpower can clandestinely retain extra nuclear weapons at the start of the agreement or violate the agreement by developing, assembling, and deploying a significant number of nuclear weapon systems that could be used to directly attack the other superpower or to achieve political gain through nuclear blackmail. Clearly, there are risks to each superpower's national security involved with this concept, just as there are risks involved with the current and the zero-nuclear-weapon states of the world. However, the issue is not the existence of risks but rather how these risks compare with the risks associated with the current and zero-nuclear-weapons states of the world.

3.5 Zero-Nuclear-Weapons Deterrence

Many prominent world leaders, including recent American Presidents, have expressed their hope for reducing the risk of nuclear war by significant reductions in nuclear weapons. In his inaugural address, President Carter described his assessment of the current state of the world and his hopes for the future:

"The world is still engaged in a massive armaments race designed to ensure continuing equivalent strength among potential adversaries. We pledge perseverance and wisdom in our efforts to limit the world's armaments to those necessary for each nation's own domestic safety. And we will move this year a step toward our ultimate goal - the elimination of all nuclear weapons from the face of the Earth. We urge all other people to join us, for success can mean life instead of death." (p. 3)

President Reagan in his March 23, 1983 address to the nation announced a national research and development effort "to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear weapons. This could pave the way for arms control measures to eliminate the weapons themselves."

This section describes the design of the zero-nuclear-weapon alternative state of the world in sufficient detail to analyze its plausibility and stability using the models we develop in subsequent chapters. The basic idea for this alternative is from Schell's alternative recommended in The Abolition. However, we make modifications to his concept and expand the political-military analysis. Since our research objective is to analyze the alternative states of the world, we do not address the issues associated with the transition from the current state of the world, or intermediate states of the world, to the zero-nuclear-weapons state.

Schell's fundamental concept is to abolish nuclear weapons but provide nuclear deterrence by each superpower retaining the <u>capability</u> to assemble, deploy, and, if necessary, to use nuclear weapons. An intentional time lag is built-in to allow additional time to resolve conflicts in a superpower crisis. Since the superpowers' fingers would not be on the trigger of world destruction, Schell believes the superpowers, and the world, would be inherently more secure. Strategic defense is permitted and encouraged to decrease the incentives to violate the agreement or activate the nuclear weapons capability.

Schell's primary motivation for developing his concept was his belief that, in the current state of the world, the fate of the earth is at risk since the use of nuclear weapons could cause tremendous destruction and, potentially, terminate the human species. Schell was compelled to rely on the capability to rearm with nuclear weapons, instead of abolishing both nuclear weapons and the capability to build nuclear weapons, because he concluded that nuclear weapons knowledge and technology can not be forgotten. He believed a world government would be required to insure that no country maintained the capability to build nuclear weapons. Since Schell believed a world government was politically impossible without major, and highly unlikely, world political change, he concluded that his form of nuclear weapon abolition was the best state of the world that was remotely achievable.

In the remainder of this section, we further describe the zero-nuclear-weapon design emphasizing the leadership beliefs, the international and domestic infrastructure, the force structure, and the arms control agreements in this state of the world.

Beliefs

In addition to the leadership beliefs described above for both alternative states, to achieve the zero-nuclear-weapons state of the world, the superpower leaders must desire to avoid the risk of nuclear forces on constant alert. They must believe that the risk of nuclear war with deployed nuclear forces exceeds the risk of undetected intentional arms control violations and the risk of the other country's undetected activation of the nuclear weapons capability. The leaderships' beliefs about the stability of the zero-nuclear-weapon state of the world also depend on their assessment of these two risks.

Infrastructure

The major political-military alliances of the superpowers are retained. Extended deterrence is provided by the following three capabilities: the deployed conventional forces, the capability to mobilize additional conventional forces, and, as a last resort, the capability to assemble and deploy the nuclear weapons capability. As in minimum deterrence, the critical issue is the European perceptions about the credibility of extended deterrence based primarily on conventional forces. However, this conventional forces coupling might be considered more credible than the current nuclear coupling since we have already come to Europe's aid with conventional forces twice in this century and the risk to the U.S. would be less without large numbers of deployed nuclear weapons. However, since the nuclear capability does exist, there would be more risk to the U.S. than the risk during World War I and World War II.

The MICs of both superpowers are responsible for four major tasks. First, the nuclear deterrent capability must be survivably maintained. Second, the other superpower's compliance with the arms control agreement must be closely monitored. Third, a very credible strategic defense must be developed and deployed. Finally, conventional forces must be maintained and credible plans developed to mobilize and deploy forces to Europe.

Force Structure

The basic concept is the abolition of all assembled and deployed nuclear weapons, both strategic and theater; however, both superpowers maintain a secure capability to assemble and deploy strategic nuclear weapons. Schell proposed a couple of weeks as the planned time delay; however, the time required to activate the nuclear capability depends on the types and quantities of nuclear weapons sanctioned by the arms control agreements. With effective strategic defenses, the details of the time delay are not critical. However, if strategic defenses are not effective, the technical and practical feasibility of various time delays would become a fundamental issue.

An important issue is the assumption made about the nuclear weapons available to allies and unaligned countries in this state of the world. Since our analysis focuses on Soviet-American issues, we make the critical assumption that third countries agree to the same type of nuclear force capabilities and arms control agreements as the superpowers, i.e., theater nuclear forces are abolished and a small strategic force capability with the same built-in time delay.

The three critical strategic nuclear force issues are the types of forces, the number of each type, and the planned time delay. Two essential decisions must be made about the type of weapons. First, should the weapon systems be air-breathing, missiles, space systems, or a combination? Second, the numbers of each type of weapon system must be decided. The minimum deterrence force levels are a possible solution. Again, the effectiveness of the strategic defense against the weapon systems is very important; however, if defense is effective against the nuclear weapon systems, the number of weapons will not be as important an issue. Finally, the importance of the details of the planned delay time depends on the confidence the decision-makers have in the arms control verification system and the strategic defense capability. If the verification system and the strategic defense capability are very good, the the details of the planned time delay will not be as important.

From a verification viewpoint, large strategic systems are more desirable. Since the nuclear capability must be survivable during the period of assembly and deployment, the superpowers would probably deploy the systems in the interior of their countries to reduce vulnerability to conventional air attack from peripheral land areas, or sea based forces, during the nuclear capability activation period. SLBMs would not be desirable since assembly must take place in one location where the submarine would be vulnerable to nuclear or conventional attack prior to being survivably deployed.

An interesting strategic system that meets several of the desired requirements is a deep underground missile basing system deployed in a mountain. The ICBMs would be large enough, and the construction requirements massive enough, to enable verification by NTM. In addition to the time to assemble the weapon systems, the system has a built-in delay in deployment. This delay could be increased by limiting the quantities of the breakout mechanisms for tunneling through the mountain to the outside, e.g., more missiles than breakout mechanisms.

Strategic defense reduces the incentives to violate the arms control agreements and, therefore, is a critical element of this state of the world and is intentionally uncontrolled. Depending on the types and numbers of nuclear weapon systems and the amount of effort the superpowers invest in defense, defense could be technically feasible against small numbers of clandestinely manufactured, assembled, and deployed nuclear systems or against all the assembled and deployed allowed nuclear weapons. Defense offers several additional advantages in this state of the world. First, the development and deployment of a strategic defense would significantly decrease the incentive to violate the agreement since it would reduce the risk of a bolt-from-the-blue attack and reduce the credibility of a blackmail threat. Second, since the defense would have to be neutralized before other targets could be attacked, strategic defense significantly increases the quantities of weapons required to attack the opponent. The larger the number of clandestine nuclear weapons required, the more likely the violation will be detected. Finally, strategic defense reduces the destruction should an accidental missile launch or an intentional war occur.

Arms Control Agreements

Weapon system research, development, and testing would be significantly restricted and monitored under the provisions of the arms control agreements. The agreements would specify the allowed nuclear offense capability; prohibit the testing, development and deployment of strategic systems with conventional warheads; and permit defense against strategic nuclear weapon systems but allow monitoring to minimize offensive capability versus ground or space targets.

According to Schell, conventional forces should be controlled; however, this is significantly more difficult than the control of nuclear forces due to the large variety of conventional weapons and the less stringent design and manufacturing requirements. The plausibility of the zero-nuclear-weapon concept is enhanced if it relies as little as possible on the control of conventional weapons. Therefore, for the same reasons as minimum deterrence, we depart from Schell's requirement for control of conventional forces except for space-based offensive weapons and strategic systems with conventional warheads.

Arms control agreements must specify significant amounts of inspection and may potentially involve some technology exchange of strategic defense technology. In addition to periodic on-site inspection, the arms control agreements might include resident inspectors in all R&D organizations, test facilities, and manufacturing plants. A critical inspection dilemma is that the nuclear weapons capability must be secure yet, at the same time, the other superpower must be allowed to inspect the locations of the nuclear weapons capability to verify compliance with the agreement. The verification provisions must also include inspection procedures to verify that the country is not violating the arms control agreements at other locations. Finally, strategic defense is stabilizing, but it is hard to verify that it does not have offensive capabilities; therefore, it may be mutually advantageous for the superpowers to jointly perform all strategic defense research and development and possibly deployment.

Summary

To be plausible and stable, the zero-nuclear- weapon state of the world must result in a very low probability that either superpower can clandestinely retain extra nuclear weapons; violate the agreement by secretly assembling and deploying the allowed nuclear weapons; or clandestinely manufacture, assemble, and deploy other unallowed nuclear weapons. The amount of risk depends on the effectiveness of the strategic defense and the ability of the verification system to detect violations. The risk would occur if a militarily significant number could be used to directly attack the other superpower or to achieve political gain through nuclear blackmail. Since it is virtually impossible that any system could be designed to guarantee a zero probability of cheating, the capability to retaliate for an attack, or respond to a nuclear blackmail, must be very survivable. Clearly, there are risks to each superpower's national security with this concept, just as there are risks involved with the current state of the world and with minimum deterrence. However, the issue is not the existence of risks but rather how these risks compare with the risks associated with the alternative states of the world.

4. POTENTIAL NUCLEAR ATTACK AND SUPERPOWER CRISIS STABILITY

In the next two chapters, we analyze the stability of the current and the alternative states of the world by assessing four types of stability. First, we consider the stability of each state when the National Command Authorities (NCA) receive notification of a potential ballistic missile attack. Second, we evaluate the stability of each state during a major superpower crisis. Third, we analyze arms procurement stability which involves the incentives each superpower has to procure weapon systems which, although not in violation of the arms control agreements, may in the long term affect the stability of the agreement. Many analysts refer to arms procurement stability as arms race stability. Fourth, we examine arms control stability which involves the incentives each superpower has to comply with or violate the arms control agreements.

We use influence diagrams as our primary analytical tool to examine the potential attack and crisis decisions in the alternative states. Section 4.1 provides a brief description of influence diagrams. Section 4.2 examines potential attack stability and Section 4.3 focuses on superpower crisis stability. Section 4.4 summarizes the results of this chapter. In the next chapter, we analyze arms procurement and control stability using a model developed by expanding the conceptual framework identified in Chapter 2.

4.1 Influence Diagrams

Influence diagrams (IDs) are an attempt to graphically depict the relevant information affecting decisions in the problem being analyzed (Howard and Matheson 1984). Influence diagrams use three symbols: blocks represent the decision nodes, circles represent the important variable (known or uncertain) nodes, and directed arcs denote that the outcome of the earlier node is relevant to an uncertain node or known prior to a decision node. Each influence diagram has associated with it a state of information which is the basic knowledge, not explicitly included in the diagram, that the decision-maker uses to assess the uncertain variables. Influence diagrams also have a rigorous mathematical interpretation, i.e., as an expansion of a joint probability density function of the uncertain random variables, that can be used to solve the decision problem.

4.2 Potential Attack Stability

Potential attack stability refers to the tense situation when the NCA receives notification of a potential ballistic missile attack on the U.S. We explicitly consider three possibilities: a warning system error, an accidental ballistic missile launch by the other superpower, and an intentional ballistic missile attack. Before beginning our analysis, we briefly describe the U.S. command, control, communication, and intelligence (C3I) system and the possible U.S. responses to warning of a potential nuclear attack.

The U.S. C3I system is composed of the warning system, the decision system, and the response system. The warning system is comprised of the sensors (i.e., signal receptors such as satellites and radars) that detect potential threatening activities and provide warning information to the NCA. The decision system includes the computer fusion system for integration and assessment of warning information and the communication links through intermediate command centers to the NCA. The response system is composed of the communications links from the NCA through the intermediate command centers to the nuclear forces. Permissive Action Links (PALs) are nuclear safety devices that are not formally considered part of the C3I system. (Bracken 1983)

Garwin (1980) describes four possible strategic nuclear response policies differentiated by the amount of confirming information available prior to determining the U.S. response decision. Launch on Warning (LOW) is a launch in response to sensor indications of an attack on the Continental United States (CONUS). Launch under Attack (LUA) is a launch after a high-confidence determination that the CONUS is under massive attack. Launch on Attack Assessment (LOAA) is a launch after determination of the intent and extent of the attack against the CONUS, including an assessment of the degree of threat to the ICBMs. Launch on Impact (LOI) is a launch after nuclear explosions have occurred on or above the CONUS.

Most strategic analysts believe that a state of the world is more potential attack stable the more time the NCA has to make his response decision. Therefore, the above four response policies are described in order of increasing stability. As we will see in the subsequent analysis, potential attack stability depends on the quantity and survivability of the strategic nuclear weapon systems in each state.

In the current and the minimum deterrence states, a large percentage of the strategic nuclear weapon systems are on constant alert and are to some degree, depending on the weapon system, vulnerable to ballistic missile attack by the other superpower. Currently, the most vulnerable strategic systems are the ICBMs; however, all of the theater nuclear forces (except for SLBMs assigned to the theater and perhaps some forces, usually a small percentage, maintained in a high state of readiness) are more vulnerable than the ICBMs.

The stability ordering of the response policies is not the same for the current theater nuclear weapon systems deployed in Europe. In fact, current NATO strategy relies on the presence of vulnerable short range nuclear forces to increase the uncertainty in the mind of the WTO military planner contemplating an attack on NATO. Unlike strategic weapon systems, a much lower percentage of theater nuclear weapon systems are kept on constant alert, i.e., the Quick Reaction Alert force. In addition, the decision times are signicantly reduced from 30 minutes for an ICBM to 10-15 minutes for an INF ballistic missile.

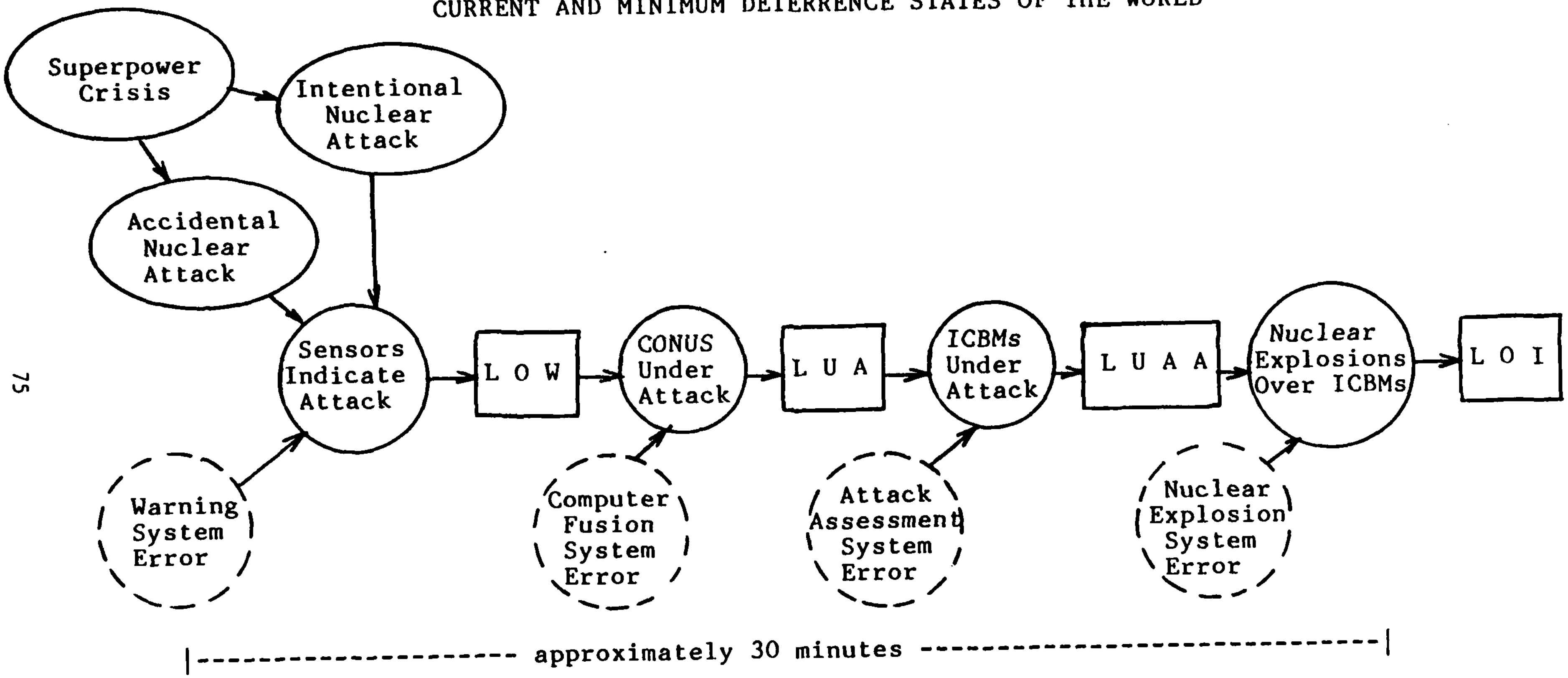
The minimum deterrence NATO strategy relies on British and French strategic nuclear forces and American conventional forces to deter a Soviet attack on Western Europe. Therefore, although the decision times are reduced because of the shorter flight times, the stability preference ordering of launch policies is the same as for strategic systems.

Influence diagrams are used to analyze the NCA's decision problem for each alternative state. The development of these influence diagrams is greatly complicated by the possibility of several limited attacks and limited responses. To get insight into the decision process, yet to keep the analysis tractable, we assume that the NCA makes one response decision but that he has several alternative responses available.

Figure 4.1 provides a partial influence diagram for the NCA's decision problem. For the minimum deterrence state, "ICBMs" should be replaced with the most vulnerable strategic system. Figure 4.2 provides a similar partial influence diagram for the zero-nuclear-weapons deterrence state. Partial influence diagrams use two major modifications to simplify the presentation of the decision problem. First, the no-forgetting arcs are not included in the diagram; the no-forgetting arcs mean that, for any decision, the decision-maker does not forget the information known at all the previous decisions. Second, since we do not analyze the decision-maker's value function, but rather focus on the differences in the IDs for each alternative,

POTENTIAL ATTACK STABILITY "PARTIAL" INFLUENCE DIAGRAM

CURRENT AND MINIMUM DETERRENCE STATES OF THE WORLD

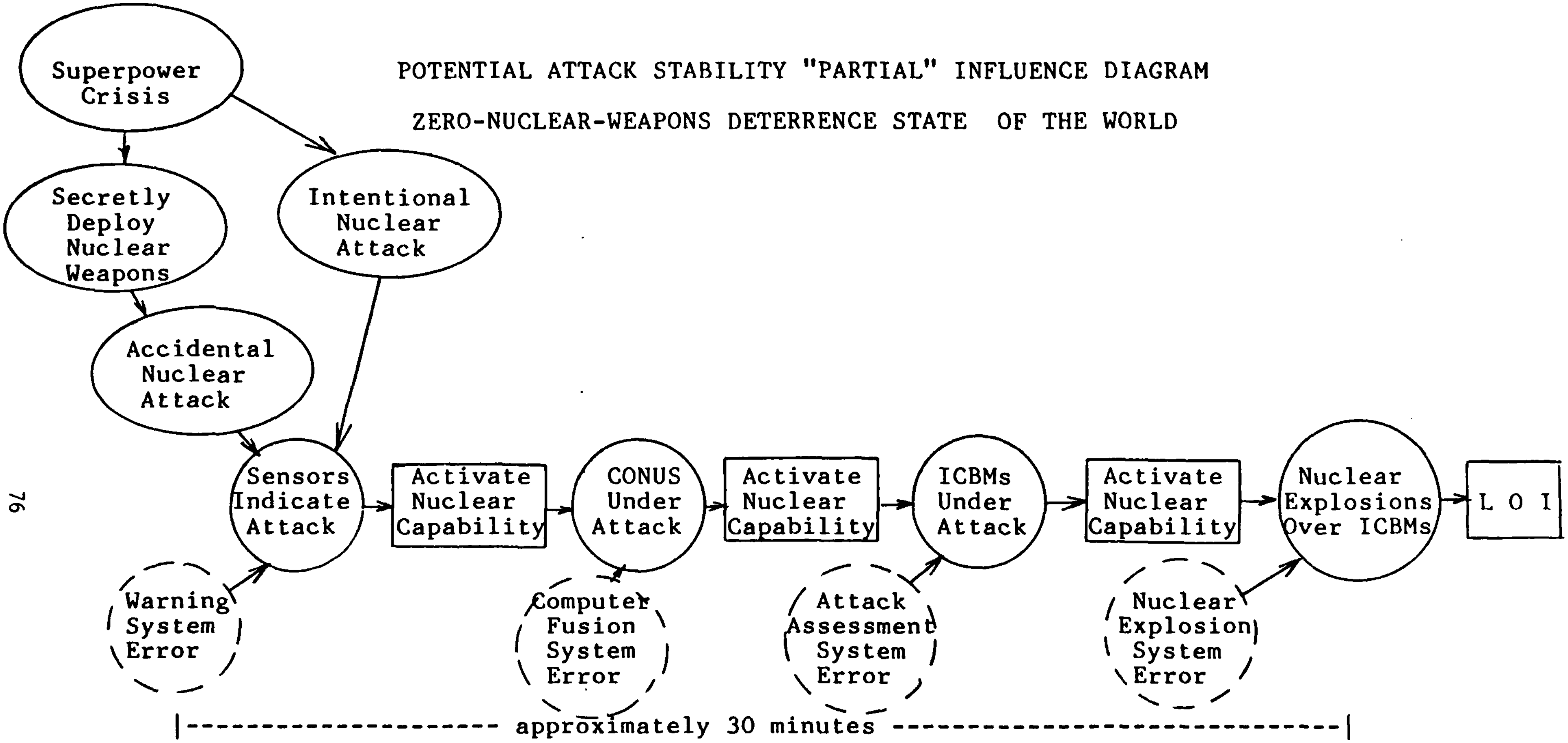


$\&_1$ and $\&_2$ = State of information of U.S. NCA in each state

Figure 4.1

POTENTIAL ATTACK STABILITY "PARTIAL" INFLUENCE DIAGRAM

ZERO-NUCLEAR-WEAPONS DETERRENCE STATE OF THE WORLD



Nuclear capability activation timeline approximately 2 weeks

$\&_{31}$ = *State of information of U.S. NCA*

Figure 4.2

the nodes and arcs from the partial ID to the value node are not included. Possible variables affecting the decision-maker's value are the following: nuclear weapon balance, conventional weapon balance, potential population loss, potential industry loss, nation-state viability, and human species survival. The state of information, i.e., all other information the NCA has available that is not explicitly modeled in the influence diagram, is different for each alternative. For example, in each state the initial number of nuclear weapons on alert varies significantly.

Zero-Nuclear-Weapons versus Current and Minimum Deterrence

First, we compare the zero-nuclear-weapon state with the other two states. When nuclear forces are on constant alert, the possibility of an accidental ballistic missile launch or an intentional attack always exists; however, in the zero-nuclear-weapons alternative, the opponent must violate the arms control agreements before an accidental or intentional attack can be launched. (The incentive to violate the arms control agreements, arms control stability, is analyzed in the next chapter.) In the current and minimum deterrence states (Figure 4.1), all four NCA response policies are available. Each of the first three policies have a finite probability of launching an attack in response to a false alarm. However, in the zero-nuclear-weapons deterrence state (Figure 4.2), the activation decision is the only nuclear decision available in the first 30 minutes. If the other country has violated the agreement and accidentally or intentionally launches nuclear weapons, the strategic defense capability will attempt to prevent or reduce the damage. After 30 minutes, the decision-maker can make his nuclear weapons activation decision based on a LOI policy. Therefore, before the activation decision is made, there is no risk of a nuclear attack in response to a false alarm in the zero-nuclear-weapons state. However, if there has been an accidental or intentional nuclear attack, the NCA has the option to respond with a conventional force attack before, during, or after he activates his nuclear capability.

Minimum Deterrence versus Current

Next, we compare the potential attack stability of the minimum deterrence state with the current state. Since the minimum deterrence levels of nuclear weapons are significantly lower, the assessment of a potential attack on the same number of weapons represents a much higher percentage of the country's strategic nuclear forces. Therefore, if the decision-maker perceives his forces are vulnerable, he will fear preemption by the opponent and have more incentive to adopt a launch policy other than LOI. If each minimum deterrence weapon system has a single warhead and is survivably deployed, the premium on preemption is reduced.

With lower numbers of nuclear weapons, the probability of an accidental launch (due to intentional or unintentional actions of the weapon system operators or custodians) might decrease, if nuclear safety precautions are more effective. Futhermore, since the number of minimum deterrence weapon systems on constant alert (each with average probability of accidental launch less than or equal to the current weapon systems on alert) is significantly lower, the probability of no accidental launches in a fixed period of time increases.

Before we analyze the effects of lower levels of nuclear weapons on alert, we must determine how to count the potential nuclear weapon "systems" vulnerable to accidental use. Due to availability of information, we consider only the U.S. weapon systems. According to Cochran et. al. (1984), there are approximately 26,000 nuclear weapons in the American stockpile managed by over 100,000 personnel in 722 military units trained for nuclear warfare. However, from a nuclear safety perspective, we want to examine the number of independent actors that could be involved in the unintentional or intentional use of a nuclear weapon on alert; for example, the crews of an ICBM launch control facility, a strategic bomber, a SLBM submarine, a submarine or surface ship with nuclear weapons (e.g. SLCM), a Pershing I or II, a GLCM, a fighter-bomber, or an Army unit with nuclear artillary.

The following analysis examines the effects of the lower levels of independent actors on the total probability of no accidental missile launches. We make two assumptions:

1. There is an order of magnitude difference in the number of independent actors - 2,500 independent actors in state 1 (current) and 250 independent actors in state 2

(minimum deterrence).

2. The average probability of an accidental launch by an independent nuclear actor does not increase in minimum deterrence. I believe this assumption is valid for two reasons. First, since fewer military personnel are required for nuclear duties, the country can be more discriminating in screening and selecting the independent actors. Second, since the number of nuclear weapon systems are reduced, more effort can be devoted per system to nuclear safety design and analysis programs.

We define the event $\mathcal{I}$ as the event that there is no accidental launch in the next year. We define p_i as the probability of an accidental launch by one independent actor in state i in the next year. If n is the number of independent actors in state i, then, from probability theory, we know that

$$[\ \mathcal{I} \mid \&_i\ ] = (1 - p_i)^n$$

Using the above information, we calculate the following probabilities as a function of p_i:

p_i	$[\ \mathcal{I} \mid \&_1\ ]$	$[\ \mathcal{I} \mid p_2 = p_1, \&_2\ ]$
.0001	.779	.975
.00001	.9753	.9975
.000001	.9975	.99975
.0000001	.99975	.999975

Two conclusions can be drawn from this analysis.

First, the lower the probability of accidental use by an independent actor, the less sensitive the overall probability of no accidental use in the next year is to a one order of magnitude reduction in the number of independent actors. Second, minimum deterrence does not result in as large a reduction in the probability of no accidental use of nuclear weapons as we might expect based on the two order of magnitude reduction in the level of nuclear weapons.

Effects of Uncertainty and Information

Finally, we consider the effects of uncertainty about the potential ballistic missile attack and the value of information about the potential attack in the alternative states. Our focus is on the NCA's decisions during the missile's flight time. Our subsequent analysis relies on relative comparisons of the alternative states; however, in an absolute sense, we should realize the awesome potential destructiveness of even one ballistic missile.

In the current state, the potential attack threatens a smaller percentage of the high levels of nuclear weapons. Therefore, uncertainty about the potential attack and the survivability of the forces under potential attack has less effect on the need to decide the response strategy during the missile's flight. In the minimum deterrence state, uncertainty about the survivability of the forces under potential attack is more important since a higher percentage of the nuclear forces are threatened by a nuclear attack.

Therefore, additional warning information and better assessment information are worth more in the minimum deterrence state.

In the zero-nuclear-weapons state the key uncertainty is whether or not the opponent is violating the arms control agreements. Therefore, we expect information about the other country's violations of the arms control agreements to worth more in this state than the other states. However, if the country perceives it has effective strategic defense, the country will not have a high value of information about the other country's violations.

4.3 Superpower Crisis Stability

Crisis stability refers to the stability of the state of the world in a major superpower conflict of interest that has the potential to escalate to conventional and/or nuclear war. Figure 4.3 is a grossly simplified influence diagram of the crisis process from the perspective of a single decision-maker, the U.S. NCA; it assumes only two sets of decisions and no interaction or communication between the superpowers during the crisis. In reality, many different decisions are made sequentially with significant interaction between the superpowers. The ID can be separated into three phases: crisis prevention, crisis management, and war termination. The crisis prevention phase involves the strategic interactions that usually prevent the conflict of interest from becoming a major superpower crisis with the potential to escalate to war. The war termination phase includes the termination of hostilities once a conventional

MAJOR SUPERPOWER CRISIS "PARTIAL" INFLUENCE DIAGRAM

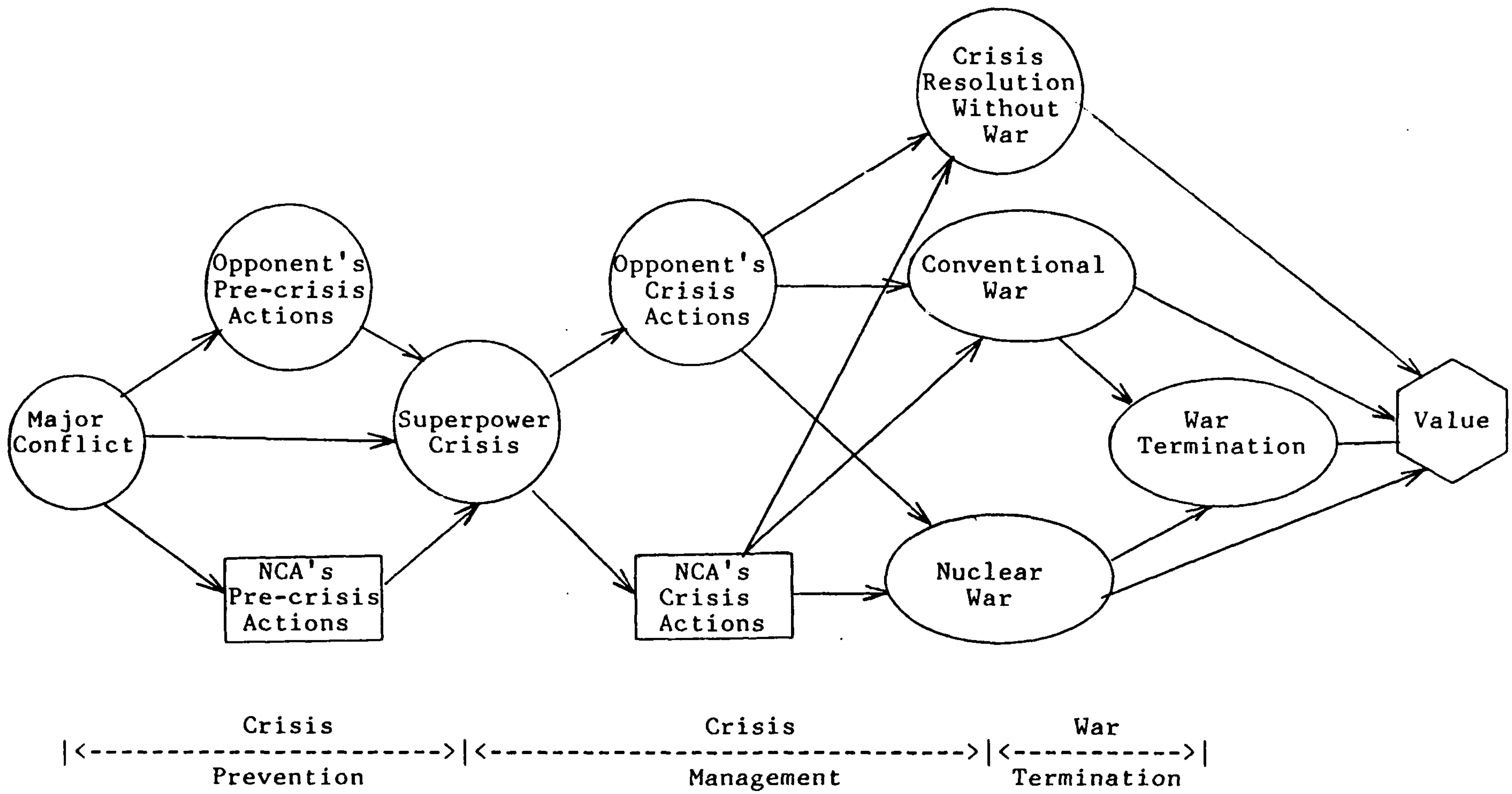
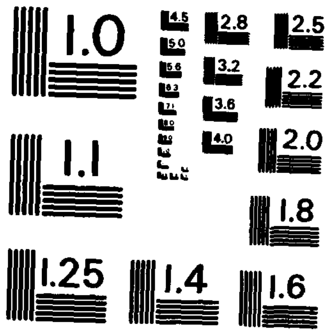


Figure 4.3

AD-A160 673 LARGE BILATERAL REDUCTIONS IN SUPERPOWER NUCLEAR WEAPONS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH G S PARNELL JUL 85 AFIT/CI/NR-85-104D 2/3

UNCLASSIFIED F/G 5/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

and/or nuclear war has occurred. We focus our analysis on the crisis management phase, which includes the decisions made during a superpower crisis that result in either crisis resolution or military conflict.

The partial influence diagram in Figure 4.4 provides a more realistic general model of the crisis management phase. The "decision" in Figure 4.3 is really a sequence of political-military decisions and it is not known which decision is the final decision until the crisis is resolved or has resulted in war. All three states of the world involve these general types of political-military decisions during a crisis.

Current versus Alternative States

In evaluating the crisis stability of the three states, the central issue is the change in the probability of war for the states with significantly less nuclear weapons. Many analysts have argued that the probability of nuclear war would increase since the potential destruction, should war occur, would be less. This is also the fundamental issue in providing politically acceptable extended deterrence to the NATO allies.

A second related crisis stability issue in the minimum deterrence state (and zero-nuclear-weapons state once the nuclear capability has been activated) is the incentive to preempt if there exists an advantage to the side striking first because of the lower levels of nuclear weapons. The potential for this advantage exists only if one country relies on what the other country believes to be vulnerable

CRISIS MANAGEMENT "PARTIAL" INFLUENCE DIAGRAM

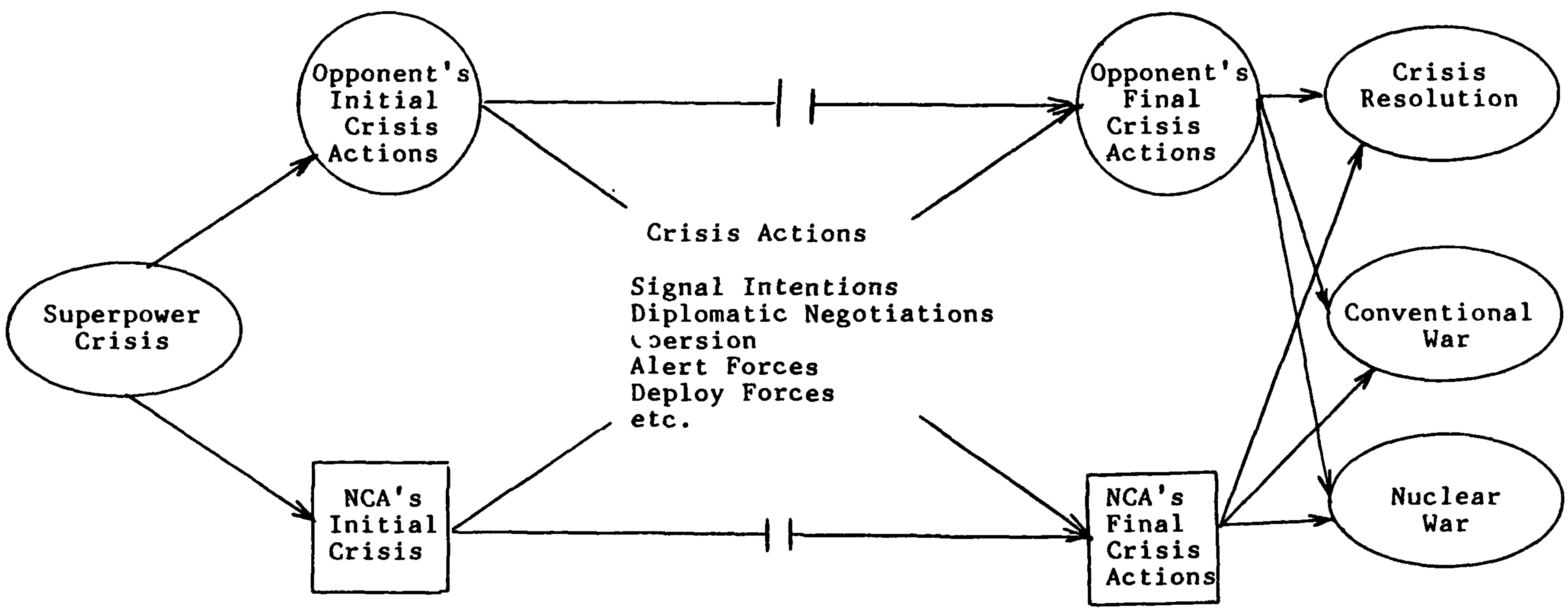


Figure 4.4

nuclear weapon systems. Therefore, the survivability of the nuclear forces is a very important design issue for the two alternative states. Again, the minimum deterrrence design feature of single warhead systems reduces the premium for preemption.

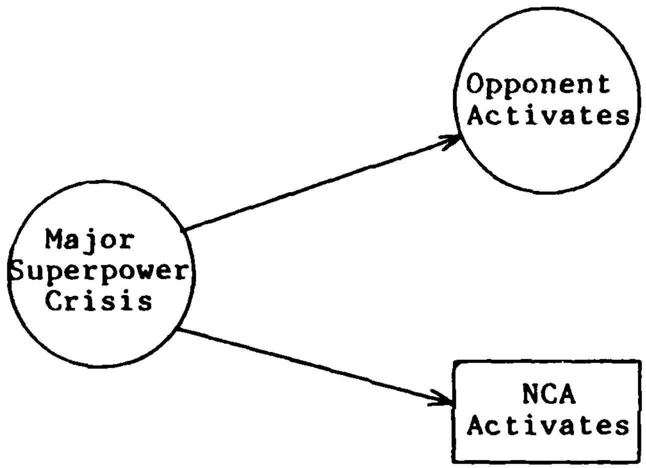
In the zero-nuclear-weapons state of the world, the same argument as above applies to the opponent's incentive to preempt with nuclear or conventional force against the nuclear weapons capability. To enhance crisis stability, the opponent must perceive that the other superpower's nuclear capability is highly survivable during peacetime and during the capability activation period.

Since no nuclear forces are on alert in the zero-nuclear-weapons state an additional decision is involved. This decision is best demonstrated by the partial IDs and decision trees shown in Figure 4.5. This problem can be thought of as a prisoner's dilemma since the state is more stable, i.e., nuclear war can not occur, if neither one activates its nuclear capability; however, both countries fear the potential disadvantage of not having activated its nuclear capability if the opponent has activated its nuclear capability.

The design features of the zero-nuclear-weapons state can significantly reduce the risk of the other country clandestinely activating its nuclear capability. First, if both countries have perfect information on the other country's nuclear capability activation decision, there will be no penalty for not activating the defense capability on

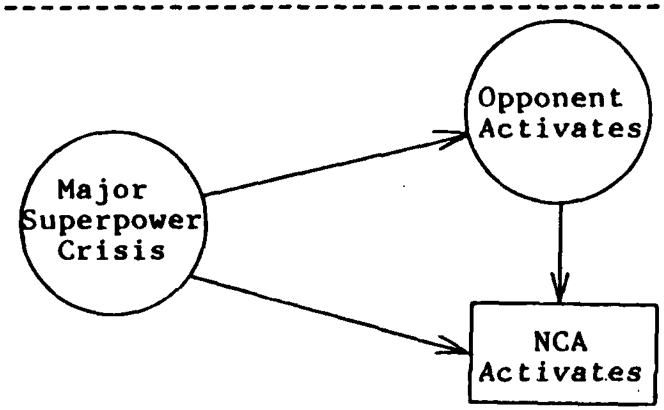
DECISION TO ACTIVATE NUCLEAR CAPABILITY

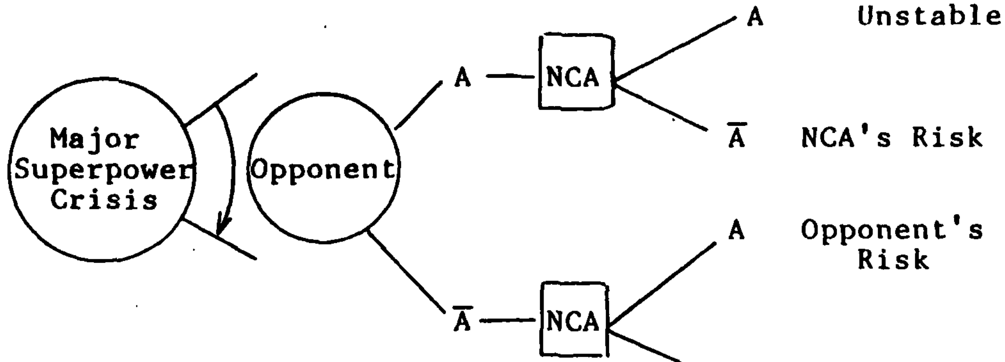
NO INFORMATION



		OPPONENT A	OPPONENT $\bar{A}$
NCA	A	Unstable	Opponent's Risk
	$\bar{A}$	NCA's Risk	Stable

INFORMATION





A = decision to activate $\bar{A}$ = decision not to activate

Figure 4.5

time. (See influence diagram with information in Figure 4.5.) Second, even without perfect information, if the strategic defense capability is effective, there will be less incentive to activate the nuclear capability. Finally, increased survivablility of the nuclear capability during activation reduces the other country's incentive to activate its nuclear capability.

4.4 Summary

Based on our analysis in this chapter, we can draw the following conclusions about potential attack stability. The zero-nuclear-weapons state is more potential attack stable, since the probability of an accidental attack is zero if ther are no violations. If the decision-maker is very confident that his minimum deterrence strategic nuclear weapons will survive an accidental attack, he should prefer minimum deterrence over the current state since the probability of an accidental attack is slightly less than the current state. However, if the decision-maker is uncertain about the survivability of his minimum deterrence forces, he may prefer the current state.

The comparison of the crisis stability of the three states of the world depends strongly on the design of the minimum deterrence and zero-nuclear-weapons states and the decision-makers' assessments about the increase in the probability of war. The critical design factors are the survivability of the nuclear forces/capability, the effectiveness of strategic defense, and the availability of information about the other country's arms control agreement violations. These three factors have a major influence on the leaders' fear of preemption in a major crisis and overall perceptions of the relative risks associated with the alternative states of the world.

5. ARMS PROCUREMENT AND CONTROL STABILITY

In the preceding chapter, we analyzed two important aspects of stability: potential attack and superpower crisis stability. However, our stability analysis for the current and alternative states of the world must also consider the the incentives to procure weapon systems that, while not in strict violation of the agreement, may erode confidence in the viability of the alternative state and the incentives to violate the arms control agreements. The purpose of this chapter is to develop an analytical model for arms procurement and control stability analysis.

As an important first step in the analysis of this problem, we formulate a static equilibrium model, instead of a dynamic model, and analyze the decisions for the next year. Our approach is essentially an application of microeconomic static equilibrium analysis. Since our research scope excludes the transition to the alternative states, a dynamic model is not essential. Clearly, a logical next step in future research would be the formulation of a dynamic model. (See Section 6.4.)

To perform this stability analysis, we model the fundamental structure of the nuclear arms procurement and control state of the world described in Chapter 2. Specifically, we expand the conceptual framework identified in Section 2.3 into a static deterministic microeconomic model in Section 5.1. In Section 5.2, we use the model to analyze cooperative and noncooperative decision-making.

Since important national security issues and major uncertainties are involved, in Section 5.3, the model is modified to include probabilistic variables. In Sections 5.4 and 5.5, the probabilistic model is used to analyze decision-making under uncertainty and the value of information.

5.1 Static Deterministic Model

5.1.1 Model Objective

The objective of the model is to analyze the arms procurement and arms control stability of the current and alternative states of the world. We assume that we can negotiate plausible arms control agreements and that we can successfully complete the transition from the current state to the alternative. We analyze the relative arms procurement and arms violation incentives of the superpowers, under cooperative and noncooperative decision-making, for each alternative state of the world.

The models developed in this chapter are static deterministic models with two decision-makers, the superpowers, and two agents, the defense industries. However, three of the four models are formulated as single decision-maker models. The decision variables are the decisions whether or not to violate the arms control agreements and the arms procurement decisions that may potentially destabilize the state of the world. The value models include the value functions of the national decision-makers (national security value function), the defense industries, and nation less the defense industries. The influence of the agents is through the relative value that the national decision-maker assigns the defense industry (versus the country less the defense industry) in his national security value model.

In our subsequent analysis, we let the superscript i denote the country (i = 1,2) and the subscript s denote the state of the world.

s = 1 current state

s = 2 minimum deterrence state

s = 3 zero-nuclear-weapons state

5.1.2 Defense Public Goods/Defense Budget.

The defense public goods are specified by the type of weapon system, the budget category, and the weapon system availability, i.e., existing, new, or future. The superpowers procure many different types of weapon systems each year. However, since we do not need to distinguish between each different weapon system, we assume that we can group all weapon systems into categories of defense public goods. (See Section 1.5.) A minimum of three defense public good categories are required to differentiate the alternatives: nuclear weapon systems, conventional weapon systems, and strategic defense. Appendix A describes a procedure for mapping the different types of weapon systems into the three defense public goods.

The number of defense public goods in our model is closely coupled to our modeling decision for the defense budget. The defense budget model could include the total budget or just important elements of the budget, e.g., procurement, research and development (R&D), and/or operations and maintenance (O&M). In order to differentiate the alternative states of the world, we include the existing weapon systems; but, O&M funding is excluded because it is not critical to our modeling objective. Since our focus is on the incentives for arms procurement, we include the procurement budget and the resulting new weapon systems. R&D is implicitly included since procurement funds will not result in weapon systems until sufficient R&D has been completed. However, R&D funding is not explicitly included since it is common to all states of the world and is difficult to model in sufficient detail to differentiate the alternatives.

Defense Public Goods

We differentiate between the existing and the new defense public goods in three categories: nuclear, conventional, and strategic defense. All nuclear defense public goods x^{i}_{sk}, for i=1,2, s=1..3, and k=1..4, are in the same currency, e.g., Kent's (1984) Standard Weapon Stations (SWS). As a result of the arms control agreements in each state of the world, the superpowers have approximately the same amount of the following two goods; however, the level of each good varies with each state of the world, s.

x_{s1} - amount of controlled existing nuclear weapons

x_{s2} - amount of controlled new nuclear weapons

The following four defense public goods are the result of each country's independent decisions. Non-zero levels would be agreement violations in the alternative states of the world but may, or may not, be a violation in the current state of the world.

x^{i}_{s3} - uncontrolled existing nuclear weapons

x^{i}_{s4} - uncontrolled new nuclear weapons

$\underline{x}_{s}$ - vector of the two mutual decision variables and the four individual decision variables.

All four conventional force goods, y^{i}_{sk}, for i,k=1,2, s=1..3, are in conventional force units, e.g., Armored Division Equivalents (ADE) (Posen 1984).

y^{i}_{s1} - amount of existing conventional forces

y^{i}_{s2} - amount of new conventional forces

$\underline{y}_{s}$ - vector of the above four decision variables

The units of the four strategic defense goods, z^{i}_{sk}, for i,k=1,2, s=1..3, are the maximum SWS's that could be destroyed in a full attack by the opponent. The controls on strategic defense vary with the state of the world: a fixed level in the current state, a zero level in minimum deterrence state, and no controls in the zero-nuclear-weapons state.

z^i_{s1} - amount of existing strategic defense weapons

z^i_{s2} - amount of new strategic defense weapons

$\underline{z}_s$ - vector of the above four decision variables

Defense Budget

In the short run, country i's defense procurement budget, d^i_s, is constrained by domestic political considerations. Therefore, the budget constraint is

$$0 \leq d^i_s \leq d^i_{max}$$

5.1.3 Technologies

For our modeling objectives, the most important technologies are manufacturing and first strike damage potential. Manufacturing technology converts the defense expenditures into weapon systems. The first strike damage potential is the maximum damage that a country could suffer in a first strike.

Manufacturing Technology:

In general, the manufacturing technology of the defense monopolist in each country is given by:

$$d^i_s = T^i(x^i_{s2}, x^i_{s4}, y^i_{s2}, z^i_{s2})$$

Only the new defense public goods are included in the equation. For our analysis, we set budget and conventional force units such that we can model the manufacturing technology as follows:

$$d^i_s = x^i_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2}$$

Since strategic defense is in the same units as nuclear offense, the above equation makes an optimistic assessment of the cost effectiveness of strategic defense.

First Strike Damage Potential:

The first strike damage potential must consider the existing and new offensive forces and the existing and new strategic defense since country i's damage potential from a first strike depends on country k's nuclear forces and country i's strategic defense. We define f^i_s as the first strike damage potential, measured in SWS's, resulting from the launch of country k's total nuclear weapons and offset by country i's total strategic defense capability. Therefore,

$f^i_s = F^i(\underline{x}^k_s, \underline{z}^i_s)$ or, based on our definition of $\underline{z}$,

$$f^i_s = c(y^k_{s1} + y^k_{s2}) + x^k_{s1} + x^k_{s2} + x^k_{s3} + x^k_{s4} - z^i_{s1} - z^i_{s2} \quad \text{for } i = 1,2 \quad \text{and}$$

$$f^i_3 = c(y^k_{31} + y^k_{32})$$

The parameter c is the relative destructiveness of a conventional force unit compared to one SWS. Clearly,

$0 < c < 1$ and, depending on the conventional force units chosen, c is probably quite small.

f^i_s is defined such that it is always positive and can never go negative. $f^i_1 > 0$ since there is a large number of nuclear weapons and little or no strategic defense. $f^i_2 > 0$ since nuclear forces are allowed but strategic defense is prohibited. We assume it is not possible to make f^i_2 negative in one procurement period. $f^i_3 > 0$ by definition. In state 3, nuclear weapons are prohibited and each side has a strategic defense capability to deter violations; furthermore, we assume that the strategic defense is sufficiently capable that nuclear weapons, bought in one procurement period, can not overwhelm the defense.

5.1.4 Value Functions

We model the national security value functions of each nation as a function of the value functions of the defense industry and the country less the defense industry. (See Section 1.5)

Defense Industry's Value Function.

v^i_s is the value function of the defense industry, i.e., the monopolist that provides country i's new defense public goods. To produce these goods each monopolist is provided the procurement defense budget. In general, the monopolist's value function is:

$$v^i_s = v^i(x^i_{s2}, x^i_{s4}, y^i_{s2}, z^i_{s2}, d^i_s)$$

In our analysis, we use the following model:

$$v^i_s = d^i_s$$

This model has two interesting interpretations. First, we can interpret the model to mean that the decision-maker's value depends directly on the defense industry's value, which is linearly proportional to the total defense spending. If the defense spending increases, then the value of the defense industry increases, and, therefore, the decision-maker's value increases. The above model has a second important interpretation; v_s^i can be considered the direct value assigned to defense spending. In this interpretation, the defense industry is only an incidental beneficiary of the defense spending on weapon systems. The results of this dissertation can be viewed with either interpretation; however, for consistency, we use the first interpretation. To assess the sensitivity to our assumption that $v_s^i = d_s^i$, in Section 5.2.3, we assume that the defense industry value is only a fraction of the defense spending, and we analyze the resulting changes in the arms procurement and control incentives.

Value Function of Country Less Defense Industry

The second value function for each country, u_s^i, is the value of the rest of the country, i.e., government, non-defense industry, citizens, etc.. We assume that we can locally (i.e., for changes in one procurement period) assess each alternative arms procurement and control state of the world by considering only the probability of nuclear war, the damage should war occur, and the cost of defense. As we noted in Chapter 1, these three factors are the generally accepted objectives of arms control. Therefore, we model the value function as follows:

$$u^i_s = u(w^i_s, f^i_s, d^i_s).$$

First, to model the probability of nuclear war, we define the event that nuclear war will occur in the next year and define w^i_s as country i's assessment of the probability that the event occurs in state s. Since the probability may change in the alternative states of the world and its assessment is critical to our analysis, we analyze w^i_s further below. Second, we use the potential damage from a first strike by the opponent, f^i_s, since it is an upper bound on the amount of damage country i would suffer in a nuclear war. Finally, we model the cost of defense as the defense procurement spending, d^i_s.

We have already defined f^i_s and d^i_s, but we need to determine the probability of war in each arms procurement and control state of the world. The probability of nuclear war is very difficult to directly assess, since there are no acknowledged experts; therefore, we must do further modeling. In each state, we assume each country's assessment of the probability of war, w^i_s, depends on three factors. First, it depends on the inherent probability of war in that state, w_s, due to the possibility of a fundamental conflict of interest between the superpowers that could lead to war. Second, it depends on country i's perception of the change in the probability of war caused by the new weapon systems procured by each country. Finally, the country's assessment depends on how sensitive the country is to the relative difference in new weapons. Our general model is the following:

$$w^i_s = w^i(w_s, \underline{x}_{s2}, \underline{x}_{s4}, \underline{y}_{s2}, \underline{z}_{s2}).$$

A key element of the security dilemma is that country 1's new weapons increase its security but that country 2's new weapons decrease country 1's security. For our analysis, we use a linear model since it captures the fundamental structure (i.e., the complementarity of defense public goods) and simplifies the subsequent analysis; however, a nonlinear model could be used and the basic results of the analysis would not change. For states 1 and 2, our model is the following:

$$w^i_s = w_s + k_s(x^k_{s4} - x^i_{s4} + y^k_{s2} - y^i_{s2} + z^k_{s2} - z^i_{s2}).$$

State 3's probability of war model does not include strategic defense, since strategic defense is not destabilizing. Therefore, our model is the following:

$$w^i_3 = w_3 + k_3(x^k_{34} - x^i_{34} + y^k_{32} - y^i_{32})$$

Of course, $0 \le w_s, w^i_s \le 1$.

The parameter k_s is the rate of change in the probability of war due to a one unit increase in defense weapons (and, by our modeling assumptions, procurement spending) by the opponent. We make the conservative assumption that the decision-maker is more worried about weapons changes at lower levels of nuclear weapons, therefore,

$$k_3 > k_2 > k_1 .$$

According to deterrence theory, three major variables affect the probability of nuclear war in state s, w_s. First, because of the nuclear predicament of mutual assured destruction, the probability of nuclear war depends on the second strike deterrent capability, s^i_s, since the destructiveness of the retaliatory second strike deters the opponent from initiating a first strike. The second strike is the maximum number of country i's nuclear weapons, measured in SWS's, penetrating the opponent's strategic defense on a second strike after surviving a first strike by all of the opponent's nuclear forces. Therefore,

$$s^i_s = S^i(\underline{x}_s, \underline{z}_s).$$

Second, the probability of nuclear war depends on the conventional forces, since the conventional force balance, b^i_s, affects the likelihood of conventional war which could escalate to nuclear war. In terms of our defense products, the conventional force balance is:

$$b^i_s = B^i(\underline{y}_s).$$

Finally, the probability of nuclear war depends on the theater nuclear force balance, t^i_s, that is used to offset any conventional force imbalance:

$$t_s^i = H^i(\underline{x}_s, \underline{y}_s).$$

For our analysis, we do not further model w_s. We assume we can assess the probability of war in each state of the world based on consideration of the factors described above. Since most analysts believe that, ceteris paribus, war is more likely when the potential devastation is less, we make the worst-case assumption that

$$w_1 < w_2 < w_3.$$

This assumption is not as straightforward as it seems. The assumption that $w_1 < w_2$ is reasonable, since states 1 and 2 are basically similar; the major difference is the number of nuclear weapons on alert. Our assumption is more valid, for state 3, once the nuclear capability has been activated; however, before the nuclear weapons capability has been activated, the probability of accidental war is reduced, and the built-in time delay allows time for the resolution of the crisis short of war. Therefore, it could well be that $w_3 << w_1$.

Using the variables we have defined above, we model the value function as follows:

$$u_s^i = a\, w_s^i\, f_s^i + (1-a)\, d_s^i.$$

Since we are going to minimize u_s^i, the model implies that the decision-maker prefers, ceteris paribus, lower expected destruction and less defense spending. The paramenters a and (1-a) are the values the decision-maker assigns the expected destruction and the defense procurement spending. For simplicity in the subsequent analysis, we normalize these parameters to sum to one. This is permissible, since it is the ratio of these parameters that matters and not their absolute value.

<u>National Security Value Functions</u>.

The national security value function of each country depends on the value functions of the country less the defense industry and the defense industry.

$$W^i_s = W(u^i_s, v^i_s)$$

Figure 5.1 is an influence diagram each country's decision problem in each state of the world. Each state of the world has the same arms procurement and control influence diagram but a different state of information and, therefore, a different assessment of the variable values. (See Section 4.1 for a short discussion on influence diagrams.) In our deterministic model, we use the expected value of the probability of nuclear war in the next year and, in general, we anticipate different values for each alternative state of the world.

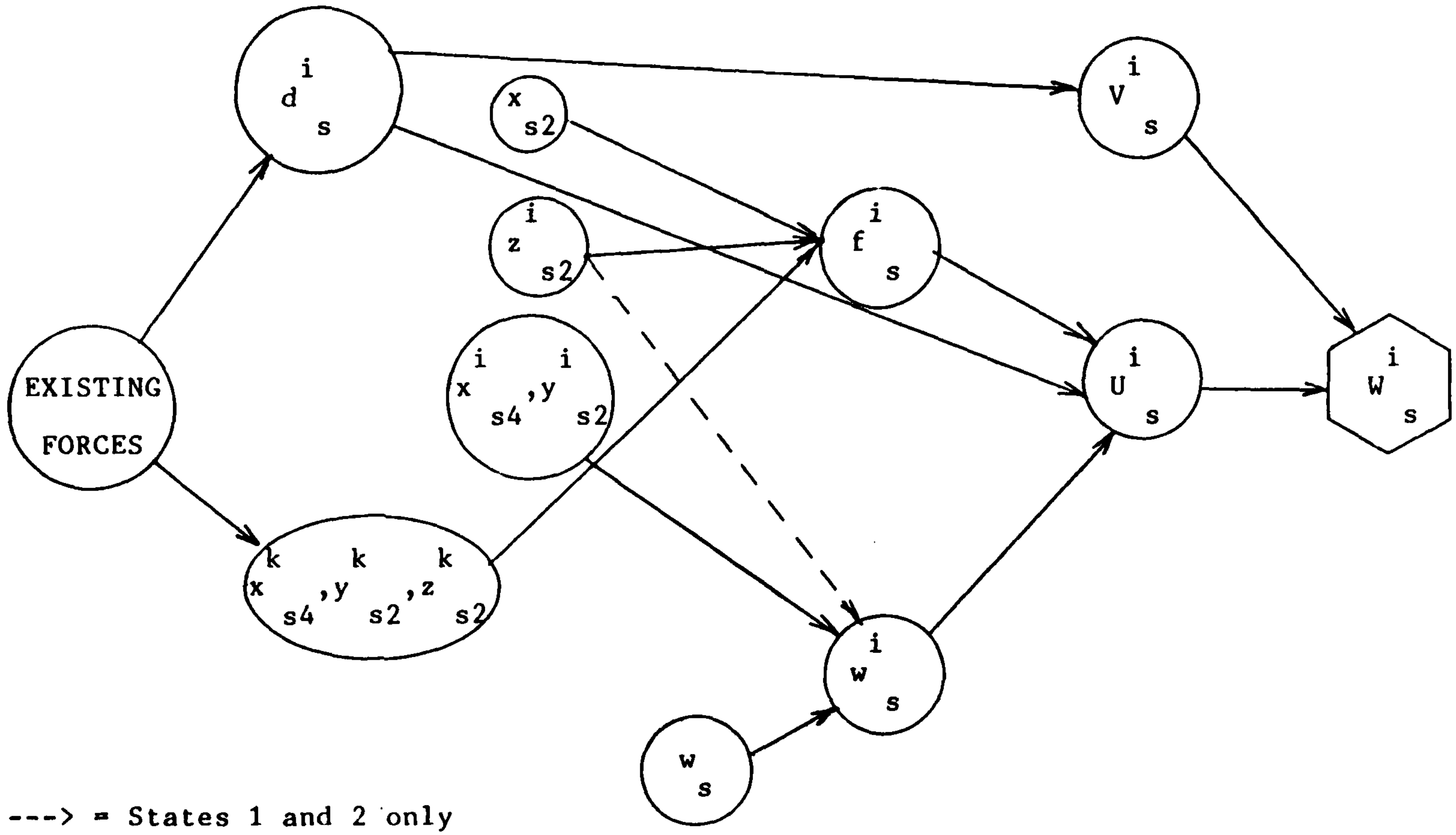
In our analysis, we use the following national security value model:

$$W^i_s = b\, u^i_s - (1-b)\, v^i_s$$

The paramenters b and (1-b) are the values the decision-maker assigns the nation's value and the defense industry's

INFLUENCE DIAGRAM FOR ALL THREE STATES OF THE WORLD

BUT THE STATE OF INFORMATION, $\&_s$, DEPENDS ON THE STATE OF THE WORLD



---> = States 1 and 2 only

Figure 5.1

value in determining the national security value. For simplicity in the subsequent analysis, we normalize these parameters to sum to one. This is permissible, since it is the ratio of these parameters that matters and not their absolute value.

Since the objective is to minimize u_s^i and maximize v_s^i, we put a minus sign in front of the second term and minimize the function. This model implies that the national security decision-maker prefers, ceteris paribus, a lower expected destruction; however, his preference for defense spending is more complex. He prefers less defense spending, since it improves the value of the country less the defense industry; yet, he prefers more defense spending, since it improves the value of the defense industry. Therefore, the relative weights that he assigns the two value contributions determine his overall preference for defense spending.

5.2 Cooperative and Noncooperative Decision-making

5.2.1 Equilibrium Concepts.

An equilibrium concept is required to obtain a solution to the problem and analyze the arms procurement and control incentives in the alternative states of the world. We use three equilibrium concepts from microeconomic duopoly theory (collusion, Cournot-Nash, and Stackelberg) and one concept from decision analysis (control).

Collusion

In the past, nuclear arms control negotiations between the superpowers have determined the levels of the weapons included and the weapons that are excluded from the agreement. During the negotiations, each country independently assessed each offer received from the opponent, or any potential new offer under consideration, for the impact on its national security and on its negotiation position.

To evaluate the best of circumstances, we consider the case of full cooperation by the superpowers on arms procurement and arms control agreement violation decisions. Figure 5.2 is a simplified influence diagram for the assumption of "collusion", i.e., the superpowers agree to cooperate to make procurement decisions to maximize a mutual security value function determined only by the superpower national security value functions. (We can use an influence diagram since we are effectively assuming one decision-maker.) The cooperation only exists for arms procurement

COLLUSION INFLUENCE DIAGRAM

STATE OF INFORMATION, $\&_s$, DEPENDS ON THE STATE OF THE WORLD

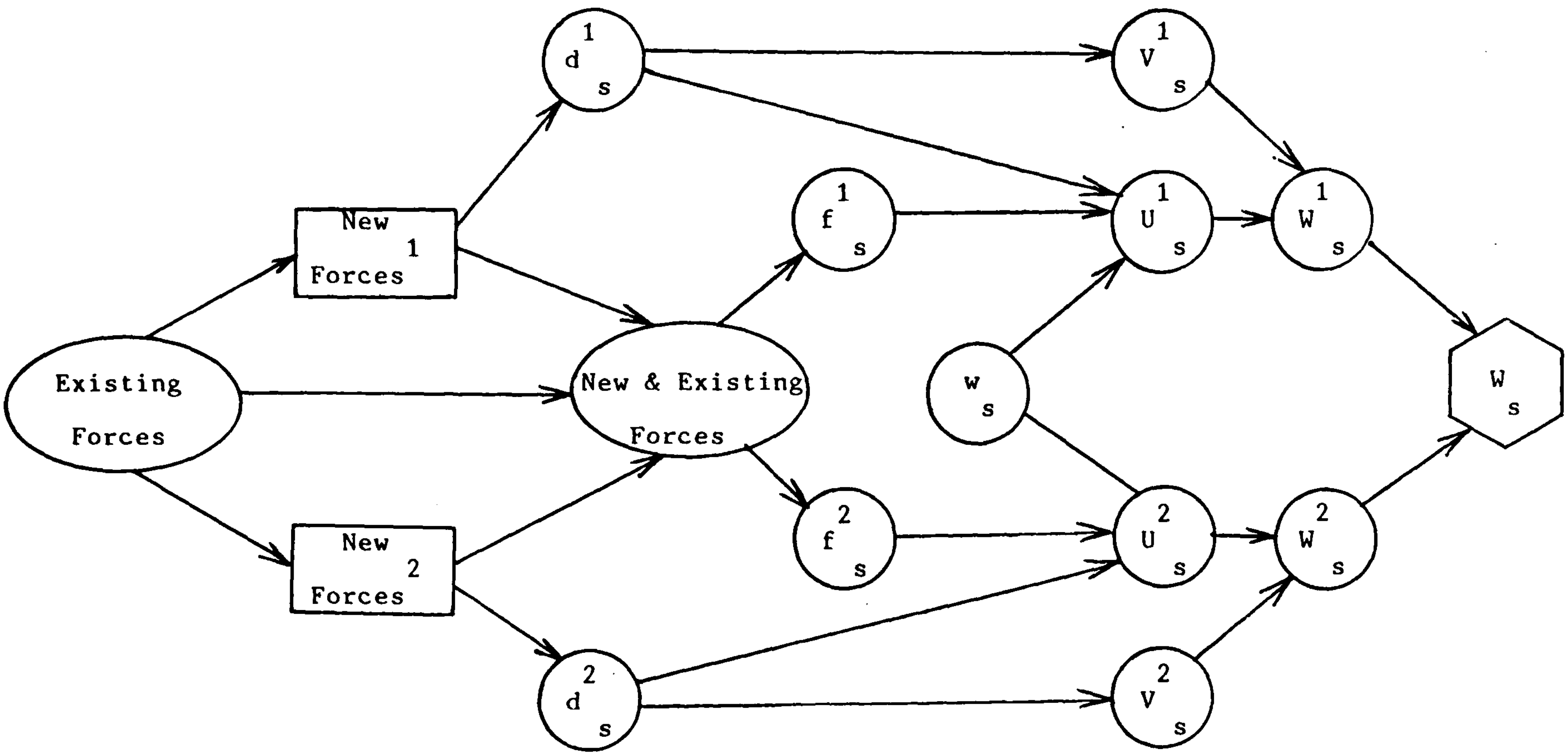


Figure 5.2

and violation decisions. There is still a finite probability of nuclear war due to the fundamental conflicts of interest between the two superpowers.

In our collusion equilibrium concept, the countries agree to maximize a mutual security value function, i.e., the sum of their national security value functions, and solve for the optimal decisions for each country. Effectively, we convert the problem to a single decision-maker problem. This approach has several advantages and disadvantages.

This concept has four major advantages. First, it focuses the attention on national security under the assumption of mutual security. Mathematically, each country must analyze its national security value function instead of "solutions". Second, since collusion results in the solution with the largest mutual security, it provides a benchmark for comparing the efficiency of the other equilibrium concepts. Third, it makes explicit each country's nuclear and conventional strategy preferences. Finally, it makes explicit the value contribution of the defense monopolies.

However, these advantages are offset by fundamental disadvantages. First, the concept requires a recognition that mutual security is the objective. Second, the information requirements are almost politically impossible. Each country would have to explicitly state its national security value function. Finally, groups in each country would strongly oppose this approach, since they could be adversely impacted by acceptance of the "optimal" solution.

Cournot-Nash.

Cournot-Nash assumes country i knows country k's defense public good levels and solves for its optimum defense public good levels. In our deterministic model, each country solves for its reaction as a function of the opponent's defense public good levels. Per microeconomic duopoly theory, if the reaction curves intersect, the equilibrium is stable since neither countries has an incentive to change its arms procurement or violation decision.

Stackelberg Behavior.

The Stackelberg concept assumes that one country is the leader and one country is the follower. The follower has a reaction function that specifies the amount of each defense public good the follower will develop as a function of the levels of the leader's defense public goods. The leader uses the follower's reaction function as its prediction of the follower's defense public goods and then optimizes its levels. With the asymmetries in our problem, it makes a difference which country is the leader and which is the follower. However, if both countries try to lead, Stackelberg Warfare occurs and the situation is indeterminate.

Control

Our final equilibrium concept is perfect control. In this concept, one country optimizes its national security value function assuming it can perfectly control the other country's arms procurement and violation decisions. In the real world, perfect control is not possible; however, since both superpowers attempt to influence the decisions of the other through political-military pressure and world opinion, the case in analytically interesting.

Equilibrium Concept Selection

The current state of the world equilibrium concept (if it is in equilibrium) involves partial cooperation on the initial conditions and a Cournot-Nash equilibrium concept. Cournot-Nash is appropriate, since the superpowers tend to view the opponent's actions as fixed, i.e., at the worst case, versus as a reaction to its decisions. Worst-case analysis is usually justified based on the major uncertainties involved.

The alternative states of the world require increased cooperation by the superpowers; but since the nation-state system is retained, collusion may not be a reasonable equilibrium concept. Because we assume the acceptance of mutual security, neither country may accept the follower position of Stackelberg behavior. Also, stability would not be enhanced if Stackelberg Warfare results. Finally, neither superpower has demonstrated the ability to control the arms procurement and violation decisions of the other. Therefore, the equilibrium concept that most closely models the current state is Cournot-Nash.

Based on the above analysis, our baseline equilibrium concept for analysis of the alternative states is Cournot-

Nash. However, to obtain insight into arms procurement and control stability of the alternatives, we also analyze the states using collusion, Stackelberg, and control equilibrium concepts.

5.2.2 Collusion

For states 1 and 2, we formulate our collusion model as follows:

$$\text{Min} \sum_{i=1}^{2} [\, b\, u^i_s - (1-b)\, v^i_s \,]$$

Subject to: for i=1,2

$$u^i_s = a\, w^i_s\, f^i_s + (1-a)\, d^i_s$$

$$v^i_s = d^i_s$$

$$w_s + k_s (x^k_{s4} - x^i_{s4} + y^k_{s2} - y^i_{s2} + z^k_{s2} - z^i_{s2}) = w^i_s$$

$$c(y^k_{s1} + y^k_{s2}) + x_{s1} + x_{s2} + x^k_{s3} + x^k_{s4} - z^i_{s1} - z^i_{s2} = f^i_s$$

$$x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} = d^i_s$$

$$x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} \le d^i_{max}$$

$$0 \le d^i_s \le d^i_{max}$$

decision variables $x_{s2}, x^i_{s4}, y^i_{s2}, z^i_{s2} \ge 0$ and constants x_{s1}, x^i_{s3}, y^i_{s1}, z^i_{s1}, w_s, and d^i_{max}.

Next, we make the substitution g = 2 b - a b -1 and use the first two equations to remove u^i_s and v^i_s from the objective function. (See Luenberger for a standard treatment of this type of analysis.) The Lagrangian is:

$$\sum_{i=1}^{2} [\, a\, b\, w^i_s f^i_s + g(x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2}) +$$

$$p^i_s [\, w_s + k_s (x^k_{s4} - x^i_{s4} + y^k_{s2} - y^i_{s2} + z^k_{s2} - z^i_{s2}) -$$

$$w^i_s] + e^i_s [\, c(y^k_{s1} + y^k_{s2}) + x_{s1} + x_{s2} + x^k_{s3} + x^k_{s4} - z^i_{s1}$$

$$- z^i_{s2} - f^i_s] + h^i_s (x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} - d^i_{max}) +$$

$$n^i_s (0 - x^i_{s4}) + c^i_s (0 - y^i_{s2}) + l^i_s (0 - z^i_{s2})] +$$

$$m_s (0 - x_{s2})$$

The first order necessary conditions give us the following equations:

$$w^i_s : p^i_s = a\, b\, f^i_s$$

$$f^i_s : e^i_s = a\, b\, w^i_s$$

We use the above two equations in the next four equations:

$$x_{s2} : \quad m_s = 2\, g + a\, b\, (w^1_s + w^2_s) + h^1_s + h^2_s \qquad (5.1)$$

$$x^i_{s4}: n^i_s = g + k_s a b (f^k_s - f^i_s) + a b w^k_s + h^i_s \quad (5.2)$$

$$y^i_{s2}: c^i_s = g + k_s a b (f^k_s - f^i_s) + c a b w^k_s + h^i_s \quad (5.3)$$

$$z^i_{s2}: l^i_s = g + k_s a b (f^k_s - f^i_s) - a b w^i_s + h^i_s \quad (5.4)$$

The complementary slackness conditions are:

$$h^i_s (x^i_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} - d^i_{max}) = 0$$

$$m_s (0 - x_{s2}) = 0 \qquad n^i_s (0 - x^i_{s4}) = 0$$

$$c^i_s (0 - y^i_{s2}) = 0 \qquad l^i_s (0 - z^i_{s2}) = 0 \quad (5.5)$$

and the nonnegativity conditions of the dual variables are:

$$h^i_s, m_s, n^i_s, c^i_s, l^i_s \geq 0. \quad (5.6)$$

The collusion model has 24 variables: 7 decision, 13 dual, and 4 others (w^i_s, f^i_s). The first order necessary conditions provide 24 equations: 11 partial derivatives, 9 complementary slackness conditions, and 4 equalities.

<u>With Strategic Defense</u>

First, we note an important relationship amoung the dual variables that greatly simplies our analysis:

$$l^i_s < c^i_s < n^i_s.$$

In collusion, it is never optimal to procure conventional forces or uncontrolled nuclear forces (because if we did l^i_s

would be strictly negative which contradicts the nonnegativity requirement for the dual variables). Therefore, we can only procure strategic defense, controlled nuclear weapons, or nothing. We consider four cases.

Case 1 $d^i_s = 0$ =>'s $h^i_s = 0$ and $w^i_s = w_s$

Equation (5.1) becomes: $m_s = 2g + 2abw_s > 0$ (5.7)

Equation (5.4) becomes:

$$l^i_s = g + k_s ab(f^k_{s0} - f^i_{s0}) - abw_s$$

where f^k_{s0} = the initial first strike damage potential prior to the new weapons procurement. By our design assumptions, $f^1_{s0} = f^2_{s0}$ for all s.

Therefore, by equations (5.6): $l^i_s = g - abw_s > 0$.

This inequality is a stricter requirement than equation (5.7). When we substitute for g, we obtain the following inequality:

$$b > \frac{1}{2 - a(1 + w_s)} \quad . \qquad (5.8)$$

Case 2 $d^i_s = z^i_{s2} = d^i_{max}$ =>'s $l^i_s = 0$

Solving equation (5.4) for h^i_s, we get:

$$h^i_s = -g + abw_s$$

Next, we substitute this result into equation (5.1) and get:

$$m_s = 4\,a\,b\,w_s > 0$$

From equations (5.6): $h^i_s = -\,g + a\,b\,w_s > 0$

substituting for g, we get:

$$b < \frac{1}{2 - a\,(1 + w_s)} \,. \qquad (5.9)$$

<u>Case 3</u>: $0 < z^i_{s2} < d^i_{max}$ =>'s $h^i_s = 0$ and $l^i_s = 0$

Using equation (5.4), we obtain: $g = -\,a\,b\,w_s$.

We substitute for g and obtain:

$$b = \frac{1}{2 - a\,(1 + w_s)} \,. \qquad (5.10)$$

<u>Case 4</u> In our collusion model, it is never optimal to procure controlled nuclear weapons. Suppose $x_{s2} > 0$, this implies that $m_s = 0$. Solving equation (5.1) for 2 g, we obtain:

$$2\,g = -\,2\,a\,b\,w_s - h^1_s - h^2_s$$

Next, we use equation (5.4) twice and substitute for 2 g into the following equation to obtain:

$$l^1_s + l^2_s = -\,4\,a\,b\,w_s < 0.$$

But this is a contradiction, since the above equation implies that at least one of the dual variables, l^1_s or l^2_s, must be strictly negative and must violate equations (5.6).

<u>Without Strategic Defense</u>

We modify our collusion model to delete strategic defense; we remove z^i_{s2} and l^i_s from the model and resolve the first order necessary conditions. The cases are very similar to the previous cases. Again, we note that $c^i_s < n^i_s$; therefore, in our collusion model, it is never optimal to procure uncontrolled nuclear weapons. Also, we use equation (5.3) instead of equation (5.4) in each case.

<u>Case 1</u> $d^i_s = 0$ =>'s $h^i_s = 0$ and $w^i_s = w_s$

From equation (5.1): $m_s = 2\,g + 2\,a\,b\,w_s > 0$ (5.11)

From equation (5.3):

$$c^i_s = g + k_s\,a\,b\,(f^k_{s0} - f^i_{s0}) + c\,a\,b\,w_s$$

where f^k_{s0} = the initial first strike damage potential prior to the new weapons procurement. By our design assumptions $f^k_{s0} = f^i_{s0}$ for all s. Therefore,

$$c^i_s = g + c\,a\,b\,w_s > 0.$$

This inequality is a stricter requirement than equation (5.11). When we substitute for g, we obtain the following inequality:

$$b > \frac{1}{2 - a\,(\,1 - c\,w_s\,)} \text{ approx.} = \frac{1}{2 - a}\,. \qquad (5.12)$$

The above approximation is valid for small values of $c\,w_s$.

<u>Case 2</u> $d^i_s = y^i_{s2} = d^i_{max}$ =>'s $c^i_s = 0$

We solve equation (5.3) for h^i_s: $h^i_s = - g - c\, a\, b\, w_s$.

We substitute this result into equation (5.1) and obtain:

$$m_s = 2\,(1-c)\, a\, b\, w_s > 0 \quad \text{since } 0 < c < 1.$$

Therefore, from equations (5.6) our conditions are:

$h^i_s = - g - c\, a\, b\, w_s > 0$. Substituting for g:

$$b < \frac{1}{2 - a\,(1 - c\, w_s)} \text{ approx.} = \frac{1}{2 - a} \tag{5.13}$$

<u>Case</u> <u>3</u>: $0 < y^i_{s2} < d^i_{max}$ =>'s $h^i_s = 0$ and $c^i_s = 0$

From equation (5.3) we obtain: $g + c\, a\, b\, w_s = 0$.

We substitute this result into equation (5.1):

$$m_s = 2\,(1-c)\, a\, b\, w_s > 0$$

When we substitute for g in the previous equality, we get:

$$b = \frac{1}{2 - a\,(1 - c\, w_s)} \text{ approx.} = \frac{1}{2 - a}. \tag{5.14}$$

<u>Case</u> <u>4</u> In our collusion model, it is never optimal to procure controlled nuclear weapons. Suppose $x_{s2} > 0$, this implies that $m_s = 0$. We solve equation (5.1) for 2 g:

$$2\, g = - 2\, a\, b\, w_s - h^1_s - h^2_s$$

Next, we use the above equation and substitute equation (5.3) twice to obtain the following equation:

$$c^1_s + c^2_s = - 2\,(1-c)\, a\, b\, w_s < 0.$$

But this is a contradiction since the above equation implies that at least one of the dual variables, c_s^1 or c_s^2, must be strictly negative and must violate equations (5.6).

No Defense Industry Value Contribution

Next, we consider the situation where there is no defense industry contribution to the national security value function, i.e., b = 1, but strategic defense is available.

Case 1 $\quad d_s^i = 0$

From equation (5.8) we obtain: $w_s < (1 - a) / a$

Case 2 $\quad z_{s2}^i = d_{max}^i$

From equation (5.9) we obtain: $w_s > (1 - a) / a$

Case 3 $\quad 0 < z_{s2}^i < d_{max}^i$

From equation (5.10) we obtain: $w_s = (1 - a) / a$

Next, we consider the situation without strategic defense.

Case 1 $\quad d_s^i = 0$

From equation (5.12) we obtain: $w_s > (a - 1) / c\, a$.

But $(a - 1) / c\, a < 0$, therefore, the condition is always met.

For state 3, we formulate the Lagrangian as follows:

$$\sum_{i=1}^{2} [\, a\, b\, w_3^i\, f_3^i + g(x_{32}^i + x_{34}^i + y_{32}^i + z_{32}^i) +$$

$$p^i_3 [w_3 + k_3 (x^k_{34} - x^i_{34} + y^k_{32} - y^i_{32}) - w^i_3] +$$

$$e^i_3 [c(y^k_{31} + y^k_{32}) - f^i_3] +$$

$$h^i_3 (x_{32} + x^i_{34} + y^i_{32} + z^i_{32} - d^i_{max}) + n^i_3 (0 - x^i_{34})$$

$$+ c^i_3 (0 - y^i_{32}) + l^i_3 (0 - z^i_{32})] + m_3 (0 - x_{32})$$

The *first order necessary* conditions give us the following equations:

$$w^i_3 : \; p^i_3 = a\ b\ f^i_3$$

$$f^i_3 : \; e^i_3 = a\ b\ w^i_3$$

We use the above two equations in the next four equations:

$$x_{32} : \quad m_3 = 2\ g + h^1_3 + h^2_3 \tag{5.15}$$

$$x^i_{34} : \; n^i_3 = g + k_3\ a\ b\ (f^k_3 - f^i_3) + h^i_3 \tag{5.16}$$

$$y^i_{32} : \; c^i_3 = g + k_3\ a\ b\ (f^k_3 - f^i_3) + c\ a\ b\ w^k_3 + h^i_3 \tag{5.17}$$

$$z^i_{32} : \; l^i_3 = g + h^i_3 \tag{5.18}$$

The complementary slackness conditions for state 3 are the same as equations (5.5) with s=3. The nonnegativity conditions of the dual variables are the same as equations (5.6) with s=3. In state 3, the collusion model has the same 24 variables and the first order necessary conditions provide 24 equations.

The cases are similar to the previous cases. We note that $n_3^i < c_3^i$; therefore, in our state 3 collusion model, it is never optimal to procure conventional forces.

<u>Case 1</u> $d_3^i = 0$ =>'s $h_3^i = 0$ and $w_3^i = w_3$

From equation (5.15): $m_3 = 2g > 0$

From equation (5.18): $l_3^i = g > 0$.

We substitute for g and obtain the following inequality:

$$b > \frac{1}{2 - a} \tag{5.19}$$

<u>Case 2</u> $d_3^i = z_{32}^i = d_{max}^i$ =>'s $l_3^i = 0$

We solve equation (5.18) for h_3^i: $h_3^i = -g$.

We substitute this result into equations (5.15) and (5.16) and obtain:

$$m_3 = n_3^i = 0.$$

Therefore, from equations (5.6) our conditions are:

$h_3^i = -g > 0$. Substituting for g, we obtain:

$$b < \frac{1}{2 - a}. \tag{5.20}$$

Since the two dual variables are zero, alternative optima exist; the decision-maker is indifferent between strategic defense, controlled nuclear weapons and uncontrolled nuclear weapons. However, the decision-maker does not prefer to procure conventional weapons; this anomaly occurs because, by our design assumptions, only conventional weapons can increase the potential destruction.

<u>Case 3</u>: $0 < z^i_{32} < d^i_{max}$ =>'s $h^i_3 = 0$ and $l^i_3 = 0$

From equation (5.18) we obtain: $g = 0$.

When we substitute for g, we get:

$$b = \frac{1}{2 - a} . \qquad (5.21)$$

The same results hold for the alternative optima described in case 2.

<u>No Defense Industry Value Contribution</u>

Next, we consider the effects of removing the value contribution of the defense industry from the national security value function, i.e., $b = 1$.

<u>Case 1</u> $d^i_s = 0$.

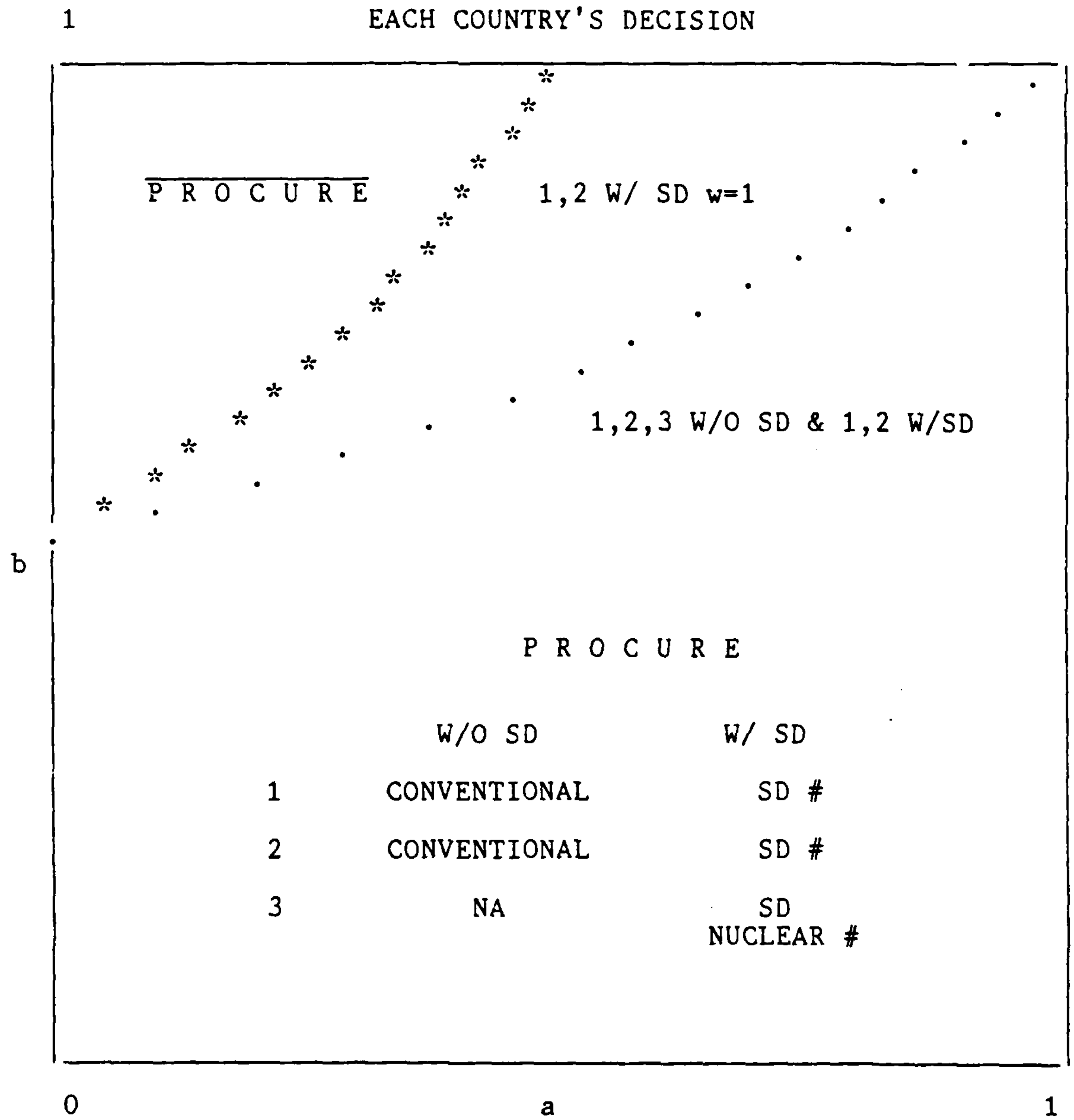
When we substitute $b = 1$ into equation (5.19), our do not procure condition becomes: $a < 1$. Since this equation is always satisfied, the decision-maker always prefers not to procure.

<u>Collusion Summary</u>

Figure 5.3 summarizes the collusion results for the complete national security value model, and Figure 5.4 summarizes the collusion results for the reduced model with no value contribution from the defense industry. We use these two types of figures to analyze all four equilibrium

COLLUSION

$$\text{MAX } W_S = W_S^1 + W_S^2$$



VIOLATION OF THE ARMS CONTROL AGREEMENTS

Figure 5.3

C O L L U S I O N

$$\text{MAX } U_S = U_S^1 + U_S^2$$

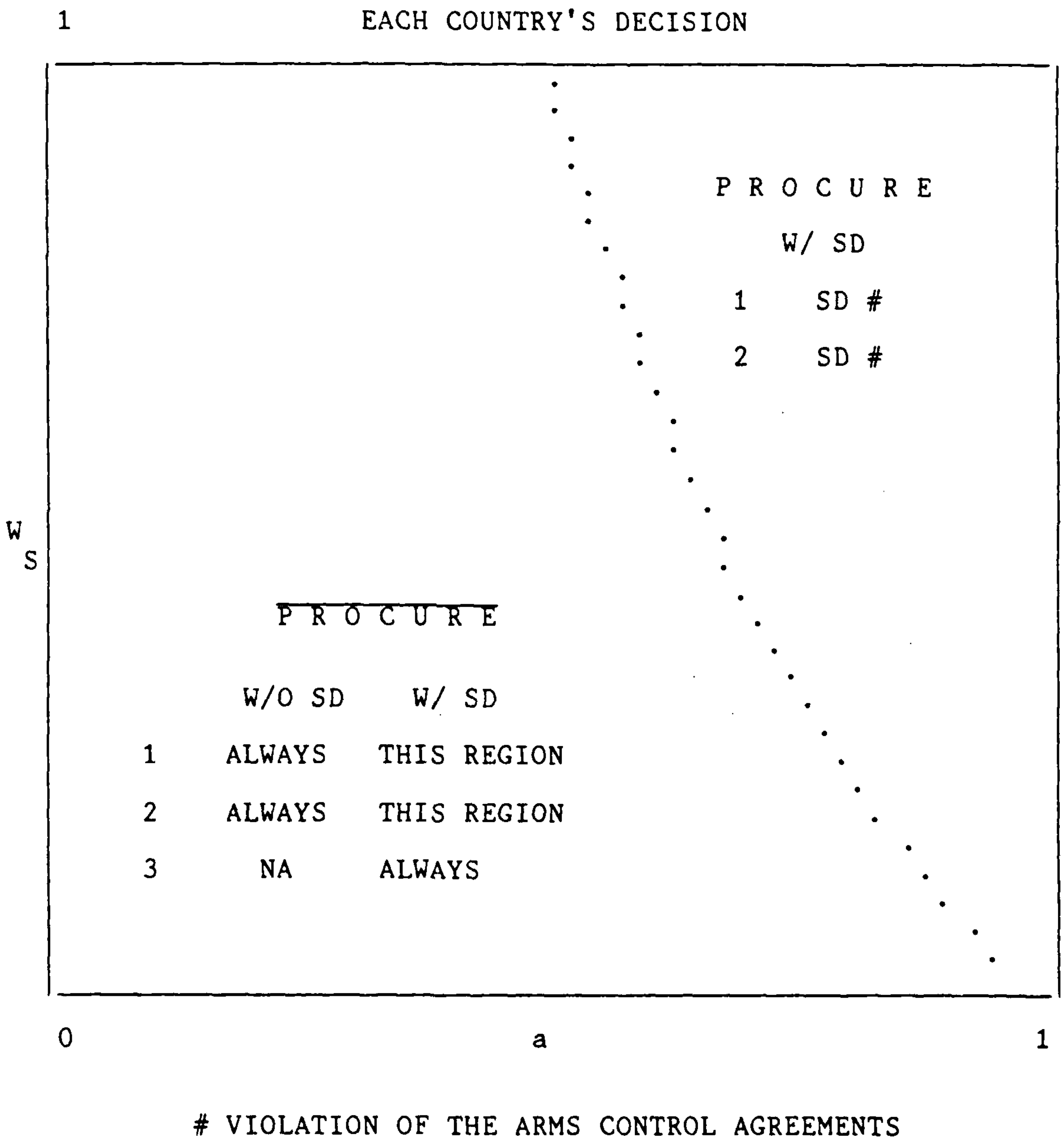


Figure 5.4

concepts. The first type of illustration (e.g. Figure 5.3) is a plot of a versus b. We recall from our model of u_s^i, that a is the weight the country less the defense industry decision-maker assigns to the expected destruction versus the weight, 1 - a, that he assigns to the procurement budget. Therefore, high (low) values of a are interpreted as high (low) concern about expected destruction versus defense spending. From our national security value model for W_s^i, we recall that b is the weight the national decision-maker assigns the value of the country less the defense industry versus the weight, 1 - b, that he assigns the value of the defense industry. Therefore, high (low) values of b are interpreted as high (low) concern about country less defense industry value versus defense industry value. Each curve plotted on the figure separates the figure into three regions. The region above the curve, marked $\overline{\text{PROCURE}}$, is the do not procure region. The region below the curve, marked PROCURE, is the region where the decision-maker's values result in a decision to spend the maximum defense budget. We define this region (including the curve) as the decision-maker's "incentive to procure" or, if the procurement violates the arms control agreements, the decision-maker's "incentive to violate the agreement". The curve itself represents the region where the decision-maker procures an optimal amount between zero and the maximum. The curves are labeled to correspond to the results of the analysis. A table is provided on the figure to summarize the optimum procurement decisions, with and without strategic defense, for each state. Finally, the symbol # denotes that the procurement decision is a violation in that state of the world.

Using the above interpretation, we next describe the results of our collusion analysis that are summarized in Figure 5.3. Without strategic defense, there is no incentive to violate the arms control agreements; if the decision-maker's values result in a procurement decision, he prefers conventional forces, because the potential destruction is less for the dollar. If strategic defense is available, there is always an incentive to violate the arms control agreements. In states 1 and 2, if the decision-maker's relative values result in a procurement decision, he prefers strategic defense, since it lowers the potential destruction for both countries. In state 3, the decision-maker prefers strategic defense or nuclear weapons, since neither one increases the potential destruction. (Recall that strategic defense is assumed to be sufficient to offset the number of nuclear weapons the opponent can procure in one period.)

The second type of illustration (e.g., Figure 5.4) is a plot of a versus an important parameter in the analysis of the particular equilibrium concept, e.g., w_s or $k_s f_s^i$. For plots of this type, we assume the decision-maker assigns no value to the defense industry value, i.e., b = 1. As before, a is the weight the country less the defense industry decision-maker assigns to the expected destruction versus the weight, 1 - a, that he assigns to the procurement budget. Therefore, high (low) values of a are interpreted as high (low) concern about expected destruction versus defense spending. Each curve plotted on the figure separates the figure into three regions. The region below the curve, marked $\overline{\text{PROCURE}}$, is the do not procure region. The region above the curve, marked PROCURE, is the region where the decision-maker's values result in a decision to spend the maximum defense budget. We define this region (including the curve) as the decision-maker's "incentive to procure" or, if the procurement violates the arms control agreements, the decision-maker's "incentive to violate the agreement". The curve represents the region where the decision-maker's procures an optimal amount between zero and the maximum. The curves are labeled to correspond to the results of the analysis. A table is provided on the figure to summarize the optimum procurement decisions, with and without strategic defense, for each state. For collusion only, a table is also provided to clarify the do not procure decisions. Finally, the symbol # denotes that the procurement decision is a violation in that state of the world.

Using the above interpretation, we next describe the results of our collusion analysis that are summarized in Figure 5.4, for the national security value function with b = 1 (i.e., no value assigned to the defense industry value function). Without strategic defense (states 1 and 2) and in state 3, there is no incentive to procure weapons, since procurement of weapons increases the budget and does not reduce the expected destruction (nuclear or strategic defense). With strategic defense (states 1 and 2), there is an incentive to procure strategic defense, since it reduces the potential destruction of both countries.

Decision-maker Preferences

In this section, we use the collusion decision-maker's national security value function to assess his preference for the three states of the world. However, to perform this analysis, we go beyond our previous assumption that our value functions are only "locally" valid.

We must consider two regions:

Region A $\quad d_3^i = 0$

$$\frac{1}{2 - a} < b \leq 1$$

The national security value functions for each state are:

$$W_1 = a\,b\,w_1\,(c\,y_{11}^1 + x_{11}^1 + x_{13}^1 + c\,y_{11}^2 + x_{11}^2 + x_{13}^2)$$

$$W_2 = a\,b\,w_2\,(c\,y_{21}^1 + x_{21}^1 + c\,y_{21}^2 + x_{21}^2)$$

$$W_3 = a\,b\,w_3\,(c\,y_{31}^1 + c\,y_{21}^2)$$

Next, we compare the value function for each state. In the following analysis, we assume that the product $c\,w_s$ is very small. The product $c\,w_s$ is the increase in the expected destruction caused by a one unit increase in conventional force spending.

$$W_2 - W_1 > 0 \quad \text{if} \quad w_2 / w_1 < f^i_{10} / f^i_{20}$$

$$W_2 - W_1 \leq 0 \quad \text{if} \quad w_2 / w_1 < f^i_{10} / f^i_{20}$$

$$W_3 - W_2 < 0$$

$$W_3 - W_1 < 0$$

<u>Region B</u> $\quad d^i_s = d^i_{max}$

$$0 \leq b < \frac{1}{2 - a}$$

The same analysis can be performed as Region A. Again, we compare the value function for each state and assume that the product $c\,w_s$ is very small. The mathematics are more tedious, but the results are the same.

If we delete the defense industry contribution from the value function, Region A applies.

The results of our preference analysis are based on several critical assumptions: cooperative decision-making, "global" national security value functions, the same order of magnitude probabilities of war in each state, and a very small product of $c\,w_s$. Based on these assumptions, state 3 is preferred to state 1 and 2. However, the preference ordering between states 1 and 2 depends on the initial weapons levels and the probabilities of war. The preferences do not depend on a or b.

5.2.3 <u>Cournot-Nash</u>

Our Cournot-Nash model corresponds to the influence diagram in Figure 5.1.

State 1 and 2

For state 1 and 2, we formulate country i's decision problem as follows:

$$\text{Min} \quad b\, u^i_s - (1-b)\, v^i_s$$

Subject to:

$$u^i_s = a\, w^i_s\, f^i_s + (1-a)\, d^i_s$$

$$v^i_s = d^i_s$$

$$w_s + k_s (x^k_{s4} - x^i_{s4} + y^k_{s2} - y^i_{s2} + z^k_{s2} - z^i_{s2}) = w^i_s$$

$$c(y^k_{s1} + y^k_{s2}) + x_{s1} + x_{s2} + x^k_{s3} + x^k_{s4} - z^i_{s1} - z^i_{s2} = f^i_s$$

$$x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} = d^i_s$$

$$x_{s2} + x^i_{s4} + y^i_{s2} + z^i_{s2} \le d^i_{max}$$

$$0 \le d^i_s \le d^i_{max}$$

decision variables x_{s2}, x^i_{s4}, y^i_{s2}, z^i_{s2} ≥ 0 and

constants x_{s1}, x^i_{s3}, y^i_{s1}, z^i_{s1}, w_s, and d^i_{max}.

We make the substitution $g = 2b - ab - 1$ and use the first two equations to remove u^i_s and v^i_s from the objective function.

The Lagrangian is:

$$a\,b\,w_s^i f_s^i + g(x_{s2} + x_{s4}^i + y_{s2}^i + z_{s2}^i) +$$

$$p_s^i\,[\,w_s + k_s\,(x_{s4}^k - x_{s4}^i + y_{s2}^k - y_{s2}^i + z_{s2}^k - z_{s2}^i) -$$

$$w_s^i\,] + e_s^i\,[\,c(y_{s1}^k + y_{s2}^k) + x_{s1} + x_{s2} + x_{s3}^k + x_{s4}^k - z_{s1}^i$$

$$- z_{s2}^i - f_s^i\,] + h_s^i\,(x_{s2} + x_{s4}^i + y_{s2}^i + z_{s2}^i - d_{max}^i) +$$

$$n_s^i\,(0 - x_{s4}^i) + c_s^i\,(0 - y_{s2}^i) + l_s^i\,(0 - z_{s2}^i) +$$

$$m_s^i\,(0 - x_{s2})$$

The first order necessary conditions give us the following equations:

$$w_s^i : \quad p_s^i = a\,b\,f_s^i$$

$$f_s^i : \quad e_s^i = a\,b\,w_s^i$$

We use the above two equations in the next four equations:

$$x_{s2} : \quad m_s^i = g + a\,b\,w_s^i + h_s^i$$

$$x_{s4}^i : \quad n_s^i = g - k_s\,a\,b\,f_s^i + h_s^i \qquad (5.22)$$

$$y_{s2}^i : \quad c_s^i = g - k_s\,a\,b\,f_s^i + h_s^i \qquad (5.23)$$

$$z_{s2}^{i}: \quad l_{s}^{i} = g - k_{s} a b f_{s}^{i} - a b w_{s}^{i} + h_{s}^{i} \qquad (5.24)$$

The complementary slackness conditions are:

$$h_{s}^{i}(x_{s2}^{i} + x_{s4}^{i} + y_{s2}^{i} + z_{s2}^{i} - d_{max}^{i}) = 0$$

$$m_{s}^{i}(0 - x_{s2}) = 0 \qquad n_{s}^{i}(0 - x_{s4}^{i}) = 0$$

$$c_{s}^{i}(0 - y_{s2}^{i}) = 0 \qquad l_{s}^{i}(0 - z_{s2}^{i}) = 0 \qquad (5.25)$$

The nonnegativity conditions of the dual variables are:

$$h_{s}^{i}, m_{s}^{i}, n_{s}^{i}, c_{s}^{i}, l_{s}^{i} \geq 0. \qquad (5.26)$$

The Cournot-Nash model for each country has 13 variables: 4 decision, 7 dual, and 2 others (w_{s}^{i}, f_{s}^{i}). The first order necessary conditions provide 13 equations: 6 partial derivatives, 5 complementary slackness conditions, and 2 equalities.

<u>With Strategic Defense</u>

First, we note an important relationship amoung the dual variables that greatly simplies our analysis:

$$l_{s}^{i} < c_{s}^{i} = n_{s}^{i} < m_{s}^{i}.$$

In Cournot-Nash, it is never optimal to procure nuclear weapons or conventional forces since l_{s}^{i} would be strictly negative which contradicts the nonnegativity requirement of equations (5.26); the decision-maker procures strategic defense or nothing and we need consider only three cases.

<u>Case 1</u> $d_{s}^{i} = 0$ =>'s $h_{s}^{i} = 0$ and $w_{s}^{i} = w_{s}$

Equation (5.24) becomes:

$$l^i_s = g - k_s \, a \, b \, f^i_s - a \, b \, w_s > 0$$

$$\text{or} \quad k_s \, f^i_s < g / a \, b - w_s \qquad (5.27)$$

<u>Case</u> <u>2</u> $d^i_s = z^i_{s2} = d^i_{max}$ =>'s $l^i_s = 0$

Solving equation (5.24) for h^i_s, we get:

$$h^i_s = - g + k_s \, a \, b \, f^i_s + a \, b \, w^i_s > 0$$

$$\text{or} \quad k_s \, f^i_s > g / a \, b - w^i_s \qquad (5.28)$$

<u>Case</u> <u>3</u>: $0 < z^i_{s2} < d^i_{max}$ =>'s $h^i_s = 0$ and $l^i_s = 0$

From equation (5.24): $k_s \, f^i_s = g / a \, b - w^i_s$ (5.29)

<u>Without</u> <u>Strategic</u> <u>Defense</u>

We modify our Cournot-Nash model to delete strategic defense (remove z^i_{s2} and l^i_s from the model) and resolve the first order necessary conditions. The cases are very similar to the previous cases. First, we note:

$$c^i_s = n^i_s < m^i_s .$$

Therefore, in our Cournot-Nash model without strategic defense, it is never optimal to procure controlled nuclear weapons. In addition, we have alternative optima; we are indifferent between procuring uncontrolled nuclear weapons and conventional forces. (We do the following analysis for conventional forces.)

<u>Case</u> <u>1</u> $d^i_s = 0$ =>'s $h^i_s = 0$ and $w^i_s = w_s$

From equation (5.23): $c^i_s = g - k_s\, a\, b\, f^i_s > 0$

$$\text{or} \quad k_s\, f^i_s < g \,/\, a\, b \tag{5.30}$$

<u>Case</u> <u>2</u> $d^i_s = y^i_{s2} = d^i_{max}$ =>'s $c^i_s = 0$

We solve equation (5.23) for h^i_s:

$$h^i_s = -\, g + k_s\, a\, b\, f^i_s > 0$$

$$\text{or} \quad k_s\, f^i_s > g \,/\, a\, b \tag{5.31}$$

<u>Case</u> <u>3</u>: $0 < y^i_{s2} < d^i_{max}$ =>'s $h^i_s = 0$ and $c^i_s = 0$

From equation (5.23): $g - k_s\, a\, b\, f^i_s = 0.$

$$\text{or} \quad k_s\, f^i_s = g \,/\, a\, b \tag{5.32}$$

<u>No Defense Industry Value Contribution</u>

Next, we consider the special case with no defense industry contribution to the national security value function, i.e., $b = 1$. The results are the same as the above except that we make the substitution: $g = 1 - a$.

Next, we show that the addition of the defense industry's value function to the national security value function strictly increases the incentive to procure. Recall from equation (5.31) that the condition to procure is:

$$k_s f^i_s > g / a\, b$$

next, we note that:

$$\frac{g}{a\, b} = \frac{b\,(2 - a) - 1}{a\, b} = \frac{1 - a}{a} + \frac{1}{a} - \frac{1}{a\, b}$$

but the last two terms are < 0 if 0 < b < 1. Therefore:

$$\frac{g}{a\, b} < \frac{1 - a}{a} \quad \text{and the incentive to procure increases.}$$

For state 3, we formulate the Lagrangian as follows:

$$a\, b\, w^i_3\, f^i_3 + g(x_{32} + x^i_{34} + y^i_{32} + z^i_{32}) +$$

$$p^i_3\, [\, w_3 + k_3\, (\, x^k_{34} - x^i_{34} + y^k_{32} - y^i_{32}) - w^i_3\,] +$$

$$e^i_3\, [\, c(y^k_{31} + y^k_{32}) - f^i_3\,] +$$

$$h^i_3\, (x_{32} + x^i_{34} + y^i_{32} + z^i_{32} - d^i_{max}) + n^i_3\, (0 - x^i_{34})$$

$$+ c^i_3\, (0 - y^i_{32}) + l^i_3\, (0 - z^i_{32}) + m^i_3\, (0 - x_{32})$$

The first order necessary conditions become:

$$w^i_3 : \quad p^i_3 = a\, b\, f^i_3$$

$$f_3^i: \quad e_3^i = a\,b\,w_3^i$$

We use the above two equations in the next four equations:

$$x_{32}: \quad m_3 = g + h_3^i \tag{5.33}$$

$$x_{34}^i: \quad n_3^i = g - k_3\,a\,b\,f_3^i + h_3^i \tag{5.34}$$

$$y_{32}^i: \quad c_3^i = g - k_3\,a\,b\,f_3^i + h_3^i \tag{5.35}$$

$$z_{32}^i: \quad l_3^i = g + h_3^i \tag{5.36}$$

The complementary slackness conditions are the same as equations (5.25) with s=3. The nonnegativity conditions of the dual variables are the same as equations (5.26) with s=3. In state 3, the Cournot-Nash model for each country has the same 13 variables and the first order necessary conditions provide 13 equations.

First, we note:

$$c_3^i = n_3^i < m_3^i = l_3^i .$$

In state 3, the decision-maker is indifferent between procuring conventional forces and uncontrolled nuclear forces; however, it is never optimal to procure controlled nuclear weapons or strategic defense, since in our model neither one reduces the expected damage. The conditions are the same as equations (5.30), (5.31), and (5.32), since equation (5.35) is the same as equation (5.23).

No Defense Industry Value Contribution

Next, we consider the effects of removing the defense industry value contribution from the national security value function, i.e., b = 1. Equations (5.30), (5.31), (5.32) apply with the substitution b = 1.

Representative Numbers

To plot the results of the Cournot-Nash analysis, we need to assume representative numbers. The following are the initial conditions used in the subsequent analysis:

State	k_s	f_s^i	$k_s f_s^i$
1	.0001	25,000	2.5
2	.001	250	.25
3	.002	25	.05

The representative numbers for f_s^i follow from the assumptions we made about each state of the world. The assumed destructiveness of conventional forces versus nuclear is c = 0.01; therefore, the destruction contribution of conventional forces is only significant in state 3. First, f_1^i was obtained by dividing the total number of nuclear weapons in half, which is roughly equivalent to the number of Standard Weapon Stations in today's world. Second, f_2^i was obtained from our assumption that the minimum deterrence levels are approximately two orders of magnitude less than the current state. Finally, f_3^i is assumed to be one order of magnitude less destructive than minimum deterrence. (Since c is quite small, this is a very conservative assumption.)

The assumed maximum procurement spending for the next period is $d^i_{max} = 100$. The representative numbers for k_s were arbitrarily determined subject to the equation for w^i_s and the following two constraints:

$$k_1 < k_2 < k_3 \quad \text{and} \quad 0 \leq w^i_s \leq 1.$$

In our Cournot-Nash analysis, we must consider the decisions of both countries. In a Cournot-Nash analysis of two firms selling the same product, we solve for each firm's reaction function to the other firm's production decision. If these continuous reaction functions intersect, we have a Cournot-Nash equilibrium, since, at the intersection point, neither firm has an incentive to change its decision. In our problem, the reaction functions are discrete; depending on its relative values of a and b, each country chooses not to procure, to procure a number between zero and the maximum, or to procure the maximum. In our subsequent analysis, we concentrate on the do not procure and the procure the maximum regions, since it is very unlikely that the relative values would be known precisely enough to fall on the boundary line. (The condition for procuring between zero and the maximum.)

Table 5.1 (also labeled Figure 5.5) provides a typology of the arms procurement and control stability situations resulting from the incentives of the two countries. This typology could be used to analyze the Cournot-Nash

ARMS PROCUREMENT AND CONTROL STABILITY TYPOLOGY

TYPE	STABILITY	PROCUREMENT INCENTIVES
I	Stable	Both countries have incentives not to procure allowed weapons or to violate the agreements.
II	Arms Procurement Stable	Both countries have incentives to procure weapons allowed by the agreements.
III	Arms Procurement Unstable	One country has an incentive to procure weapons allowed by the agreements; the other country has no incentive to procure weapons.
IV	Arms Control Unstable	One country has an incentive to procure and not violate and the other has an incentive to violate the agreements.
V	Arms Procurement & Control Unstable	One country has an incentive not to procure and the other has an incentive to procure and violate the arms control agreements.
VI	Unstable	Both countries have incentives to procure weapons in violation of the arms control agreements.

Table 5.1 (Figure 5.5)

solutions by assigning ordinal preference orderings. For example, the decision-maker's preferences may be the following: (Note: > means "is preferred to")

I > II > III, I > IV > V, and II > VI.

Clearly, these preferences are very subjective, but the stability typology offers a useful way of thinking about the arms procurement and arms violation incentives of the two countries. If the decision-maker's preferences are valid independent of the state, the ordinal preferences could be used to compare the alternative states of the world.

Cournot-Nash Summary

Figure 5.6 summarizes the Cournot-Nash results for the complete national security value function. The curves in Figure 5.6 and subsequent figures are plotted using the number of the state, i.e., 1, 2, and 3. The asterisk (*) represents the curve for state 2 with strategic defense and $w_2 = 0.1$. There are four variables: a^i and b^i for i = 1,2. Each point, (a^i, b^i) determines the arms procurement/violation decision for each country. Using the definitions in Table 5.1, each pair of points determines the type of arms procurement and control stability for each state. For example, if (a^1, b^1) and (a^2, b^2) both fall in the do not procure region, the Cournot-Nash equilibrium is Stable (Type I).

The following conclusions are based on the Cournot-Nash model. First, it is never optimal to procure controlled nuclear weapons. Second, in states 1 and 2, the decision-maker has an incentive to violate the agreement and procure

C O U R N O T - N A S H

$$\text{MAX} \quad W = W_S^i \quad i = 1,2$$

1 EACH COUNTRY'S DECISION

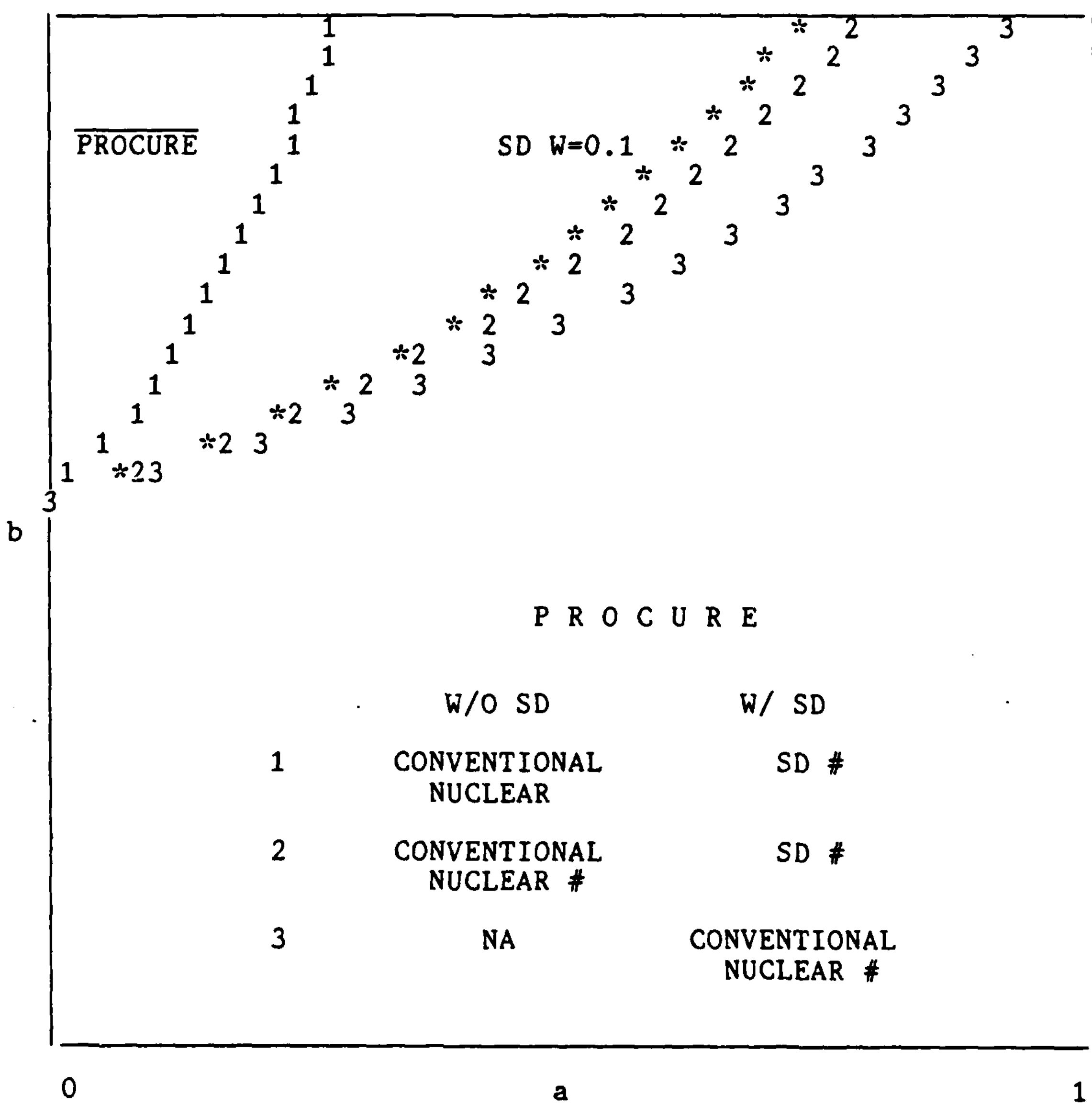


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Figure 5.6

strategic defense. If strategic defense is not available, the decision-maker is indifferent between conventional and uncontrolled nuclear weapons. Third, in state 2, the decision-maker always has an incentive to violate the arms control agreements. Fourth, in state 3, the decision-maker is indifferent between conventional and uncontrolled nuclear weapons. Finally, in state 2 with strategic defense, the decision-maker's incentive to procure is most sensitive to a perceived increase in the probability of war.

Figure 5.7 summarizes the Cournot-Nash results for the national security value function with no value contribution from the defense industry, i.e., b=1. Unlike our collusion model, the above five conclusions of the general Cournot-Nash model do not change.

Two general conclusions can be drawn from the Cournot-Nash models by examining the size of the PROCURE regions for each state (i.e., the incentive to procure) in Figures 5.6 and 5.7. First, in state 1 and 2, strategic defense increases the incentive to procure and provides an incentive to violate the arms control agreement. Second, state 1 is has the largest incentive to procure, state 2 has the second largest, and state 3 has the smallest incentive to procure.

<u>Sensitivity to Changes in Defense Industry Value</u>

In this section, we examine the sensitivity to changes in the defense industry value function, v_s^i. Specifically, revise our model as follows:

$$v_s^i = j\, d_s^i \quad \text{where} \quad 0 \le j \le 1.$$

C O U R N O T - N A S H

$$\text{MAX } U_S^i \quad i = 1,2$$

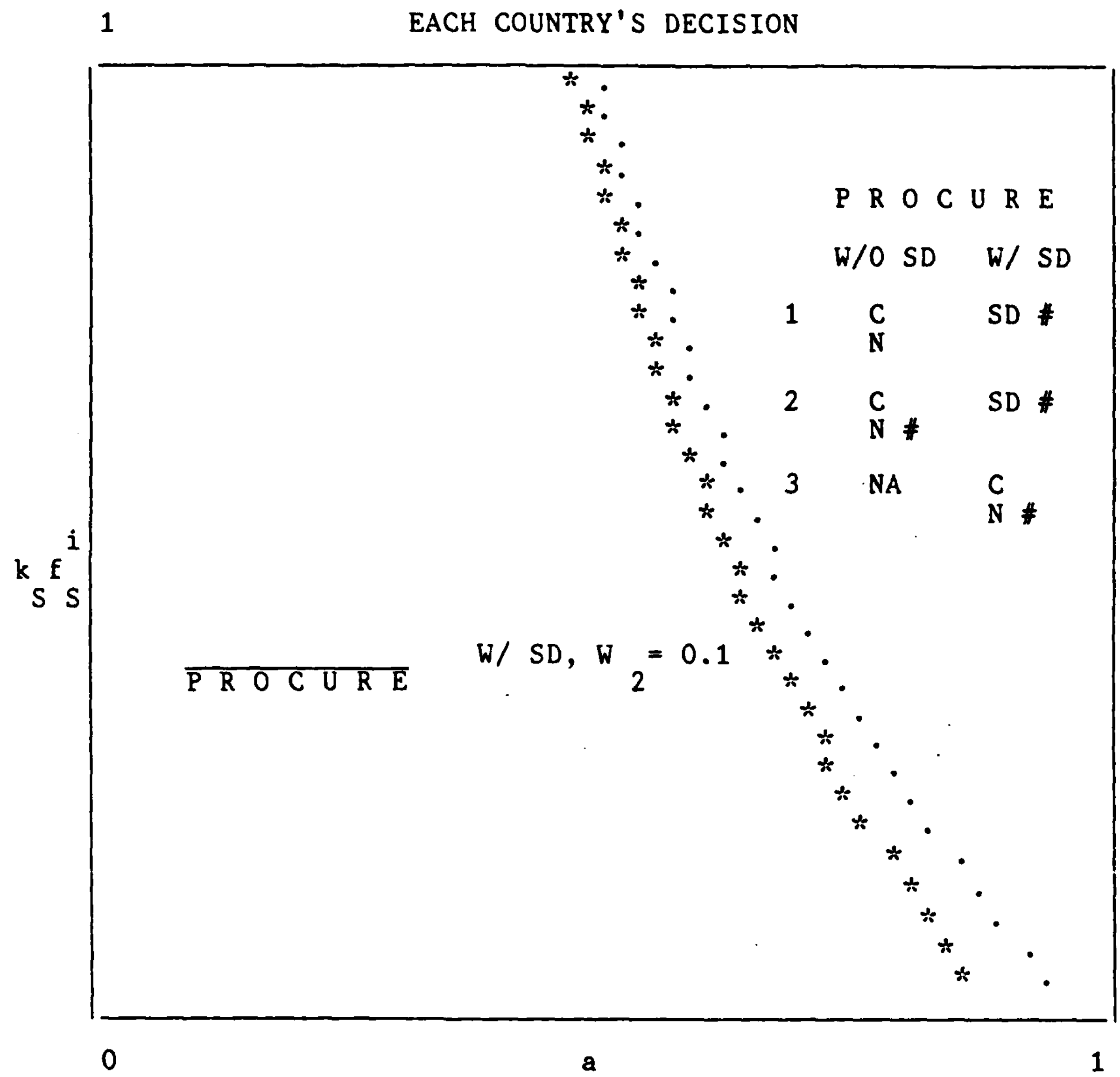


Figure 5.7

The Cournot-Nash objective function becomes:

$$\min \quad W^i_s = b\,u^i_s - (1-b)\,j\,d^i_s$$

$$\text{where} \quad u^i_s = a\,w^i_s\,f^i_s + (1-a)\,d^i_s$$

When we substitute u^i_s into the objective function, we get:

$$\min \quad W^i_s = a\,b\,u^i_s + g'\,d^i_s$$

$$\text{where} \quad g' = b\,(1-a) - j\,(1-b).$$

Therefore, all of the previous results of this chapter hold, if we substitute g' for g. Figure 5.8 summarizes the sensitivity analysis for our Cournot-Nash model for j = .1 and j = 1. For all states, the incentive to procure decreases (increases) with a decrease (increase) in j; however, the Cournot-Nash conclusions still hold, since the relative positions of the curves remain unchanged.

5.2.4 Stackelberg

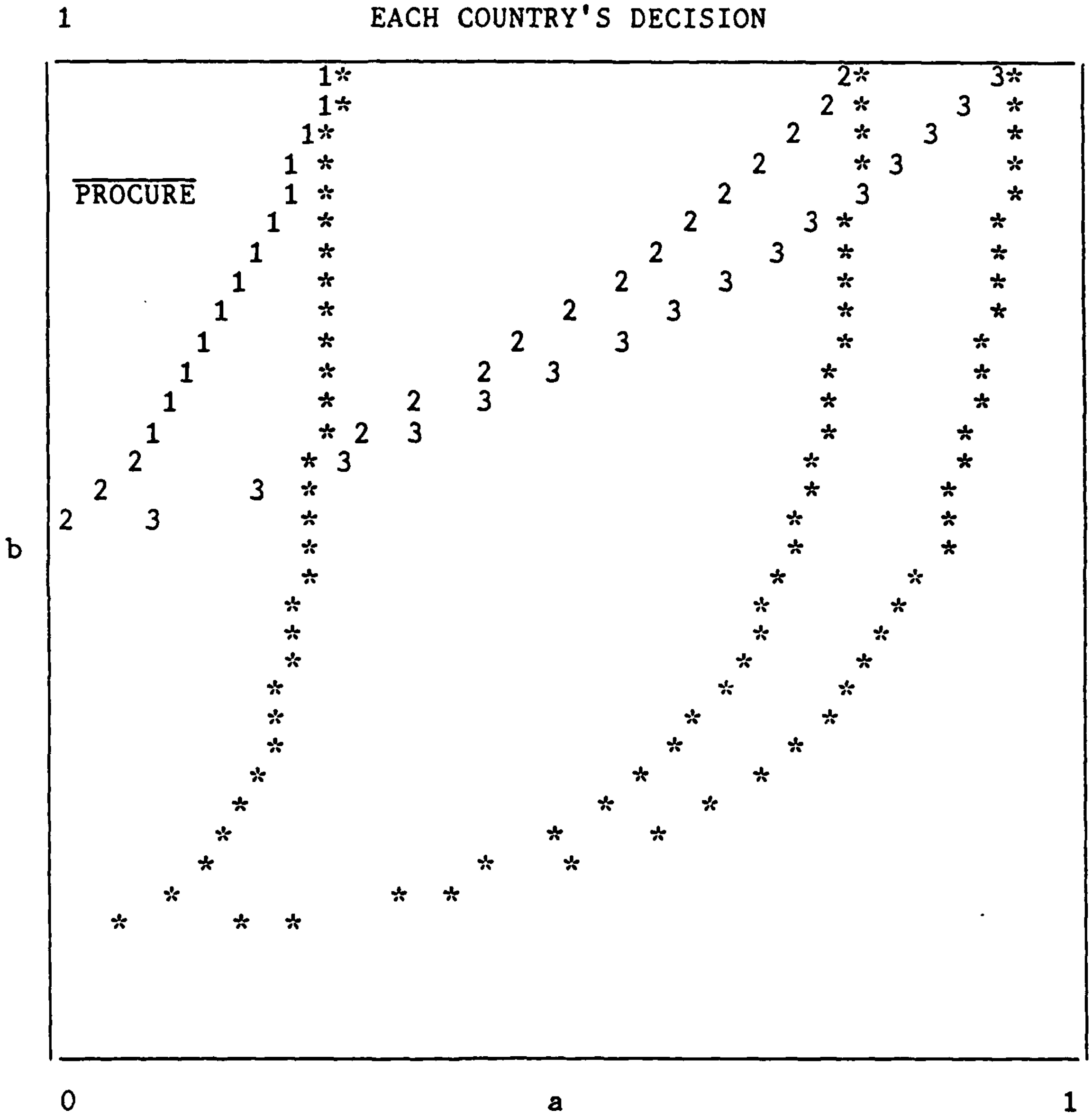
In the Stackelberg equilibrium concept, country i is the leader and country k is the follower. The leader uses the follower's reaction function to determine his optimal decision. Since the initial levels of each state are approximately the same, it makes sense to use a symmetric follower reaction function. We assume that country k uses the following leader/follower reaction function: country k agrees to make the same procurement decision as country i.

Figure 5.9 provides the decision trees for our

C O U R N O T - N A S H

$$\text{MAX } W = W^{i}_{S} \quad i = 1,2$$

$$v^{i}_{S} = j\, d^{i}_{S} \quad 0 < j < 1$$



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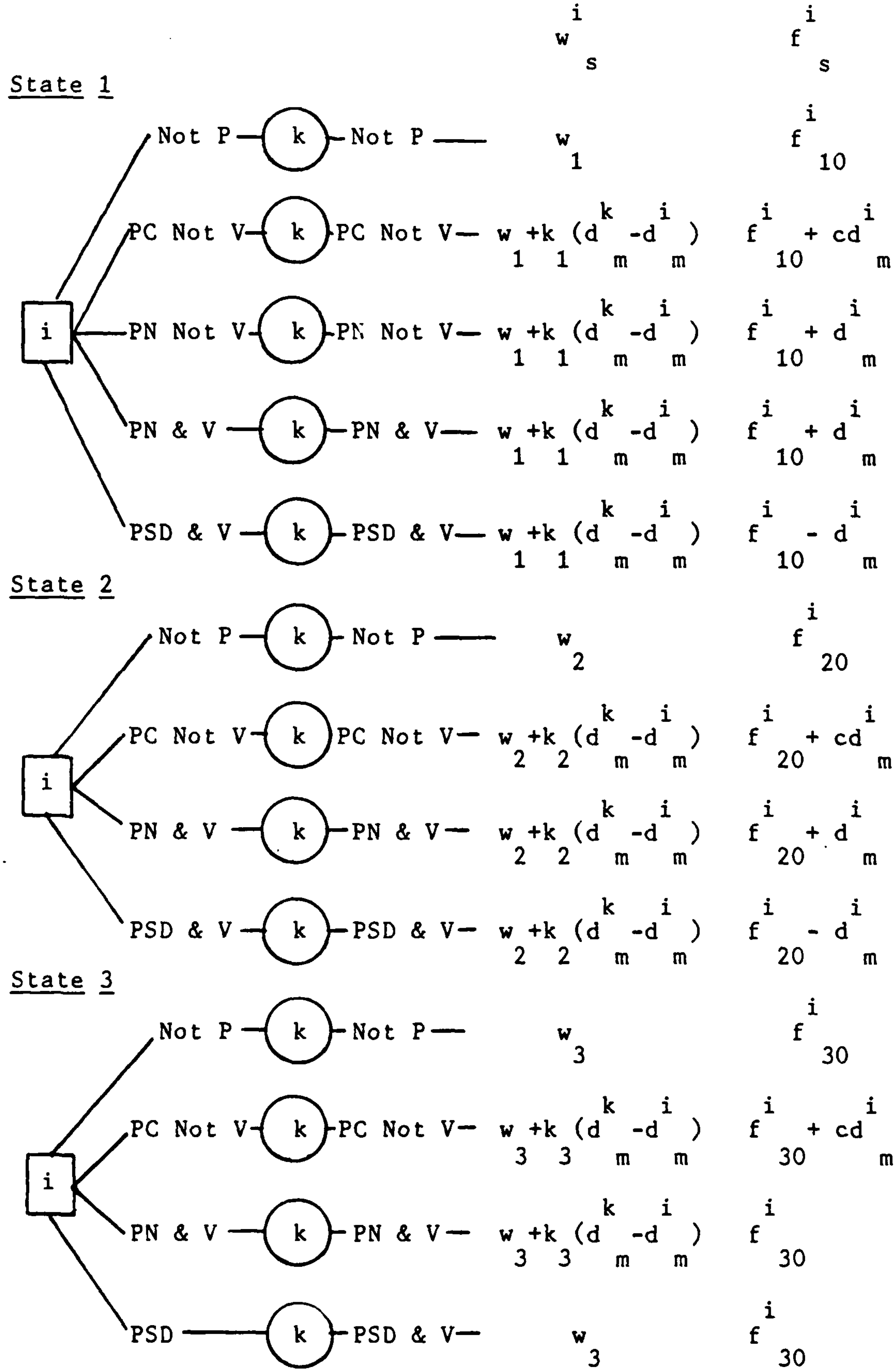
* PLOT WITH j = .1

Figure 5.8

Figure 5.9 STACKELBERG DECISION TREES



Stackelberg analysis. We use the following abbreviations:

P = Procure Not P = Do Not Procure $d^i_{max} = d^i_m$

V = Violate Not V = Do Not Violate

N = Nuclear C = Conventional SD = Strategic Defense

State 1

For state 1, by comparing the national security value functions, W^i_1, for each alternative, we can draw three conclusions from the decision tree. First, country i is indifferent between procuring nuclear weapons that violate the agreements and those that do not violate the agreements. Second, the conventional forces procurement alternative dominates the nuclear weapons procurement alternative. Third, the strategic defense procurement alternative dominates all the procurement alternatives. Therefore, country i will either not procure or procure strategic defense.

Before we analyze the two cases, we need an equation for the relative defense expenditures of the two countries. To analyze the sensitivity to changes in the follower's defense spending, we assume the follower's defense procurement spending can be within plus or minus 50 % of the leader's defense spending. Therefore,

$$d^k_{max} = r\, d^i_{max} \qquad \text{where} \qquad 0.5 \leq r \leq 1.5. \qquad (5.37)$$

With Strategic Defense

Country i will decide not to procure, if:

$$W^i_1 [\text{ Not P } | \,\&_1] < W^i_1 [\text{ PSD } | \,\&_1].$$

$\&_1$ is the state of information in state 1.

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_1 + (1 - r) k_1 (f^i_{10} - d^i_{max}) < g / a\, b.$$

Using our initial conditions, we obtain:

$$b > \frac{1}{2 - a (w_1 + 3.49 - 2.49 r)}.$$

Otherwise, country i will procure strategic defense.

<u>Without Strategic Defense</u>

Country i will decide not to procure, if:

$$W^i_1 [\text{Not } P \mid \&_1] < W^i_1 [PC \mid \&_1].$$

Again, we assume the product $c\, w_1$ is small. When we substitute the values in the decision tree and use our initial conditions, we obtain:

$$b > \frac{1}{2 - a (3.5 - 2.5 r)}.$$

This equation results in the same procurement regions as the previous case when w_1 is very small.

<u>State 2</u>

By comparing the national security value functions, W^i_2, for each alternative, we can draw three conclusions from the decision tree for state 2 in Figure 5.9. First, since controlled new nuclear weapons violate the arms control agreements in state 2, the leader has one less alternative. Second, the conventional forces procurement alternative dominates the controlled nuclear weapons procurement alternative. Third, the strategic defense procurement alternative dominates all the procurement alternatives. Therefore, country i will either not procure or procure strategic defense.

<u>With Strategic Defense</u>

Country i will decide not to procure, if:

$$W_2^i \, [\text{ Not P} \mid \&_2 \,] < W_2^i \, [\text{ PSD} \mid \&_2 \,].$$

$\&_2$ is the state of information in state 2.

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_2 + (1 - r) \, k_2 \, (f_{20}^i - d_{max}^i) < g / a \, b.$$

Using our initial conditions, we obtain:

$$b > \frac{1}{2 - a (w_2 + 1.15 - .15 \, r)}.$$

Otherwise, country i will procure strategic defense.

<u>Without Strategic Defense</u>

Country i will decide not to procure if:

$$W_2^i \, [\text{ Not P} \mid \&_2 \,] < W_2^i \, [\text{ PC} \mid \&_2 \,].$$

Again, we assume the product $c \, w_2$ is small. When we substitute the values in the decision tree and use our initial conditions, we obtain:

$$b > \frac{1}{2 - a (1.25 - .25 \, r)}.$$

State 3

By comparing the national security value functions, W_3^i, for each alternative, we can draw two conclusions from the state 3 decision tree in Figure 5.9. First, since controlled new nuclear weapons violate the arms control agreements, the leader has the same alternatives as state 2. Second, the uncontrolled nuclear weapons procurement alternative dominates the conventional forces procurement alternative; however, the strategic defense alternative does not dominate the uncontrolled nuclear weapons alternative. Therefore, three cases are possible: country i will either not procure, procure strategic defense, or procure uncontrolled nuclear weapons.

With Strategic Defense

Case 1

Country i will decide not to procure strategic defense, if:

$$W_3^i [\text{ Not P} \mid \&_3] < W_3^i [\text{ PSD} \mid \&_3].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$b > (2 - a)$$

Case2

Country i will decide not to procure uncontrolled nuclear weapons, if:

$$W_3^i [\text{ Not P} \mid \&_3] < W_3^i [\text{ PN} \& \text{V} \mid \&_3]$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$b > \frac{1}{2 - a\,(1.05 - .05\,r)}.$$

Case 3

Country i will procure strategic defense versus uncontrolled nuclear weapons, if:

$$W^{i}_{3}\,[\,PSD \mid \&_{3}\,] < W^{i}_{3}\,[\,PN \,\&\, V \mid \&_{3}\,].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$r > 1.$$

Without Strategic Defense

When strategic defense is not available, Case 2 above applies.

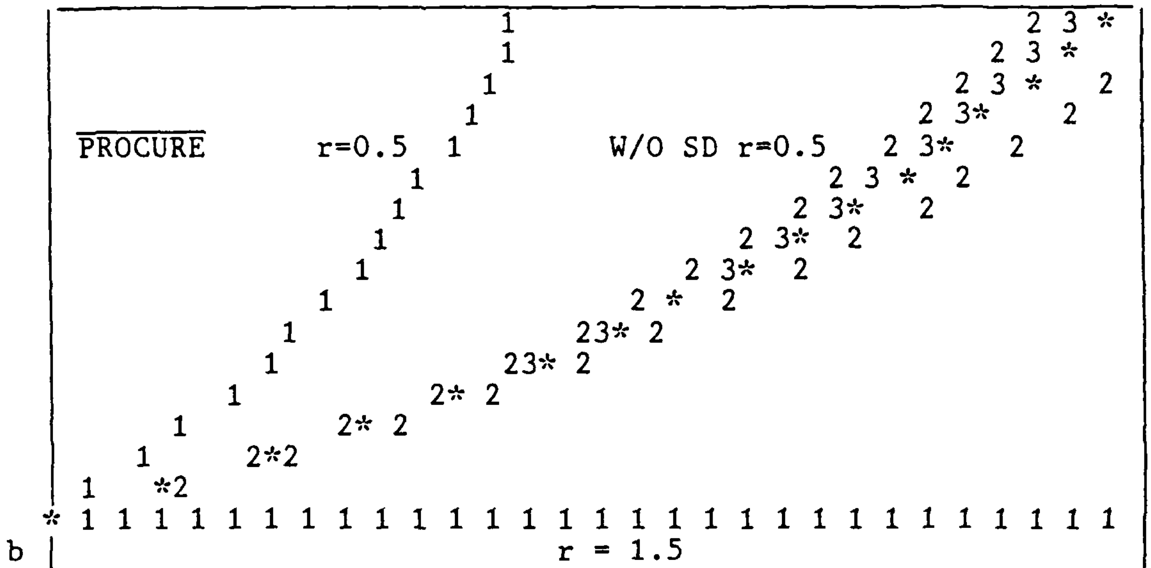
Stackelberg Model Summary

Figure 5.10 summarizes the results of the Stackelberg analysis for the national security value model with weighted value contributions from the nation less the defense industry and the defense industry. First, state 1 is the most sensitive to the other country's defense spending potential, state 2 is fairly sensitive, and state 3 is relatively insensitive to the other country's defense spending. A surprising result is that for large r the leader has less incentive to procure than the collusion decision-maker. Second, when strategic defense is available in state 1 and 2, there is an incentive to violate the agreement and procure strategic defense. If strategic

S T A C K E L B E R G

$$\text{MAX} \quad W = W_S^L$$

1 EACH COUNTRY'S DECISION



P R O C U R E

	W/O SD	W/ SD
1	CONVENTIONAL	SD #
2	CONVENTIONAL	SD #
3	NA	NUCLEAR # r < 1 SD r > 1

0 a 1

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Figure 5.10

defense is not available, there is no incentive to violate the agreement, since the leader has an incentive to procure conventional forces. Third, the leader never finds it optimal to procure nuclear weapons, since he knows that the follower will also procure nuclear weapons. Finally, in state 3, if $r \leq 1$, the leader has an incentive to procure uncontrolled nuclear weapons, since it can reduce its expected damage by reducing the probability of war. However, if $r > 1$, the leader has an incentive to procure strategic defense which, althought it does not affect the expected destruction, increases the defense industry value.

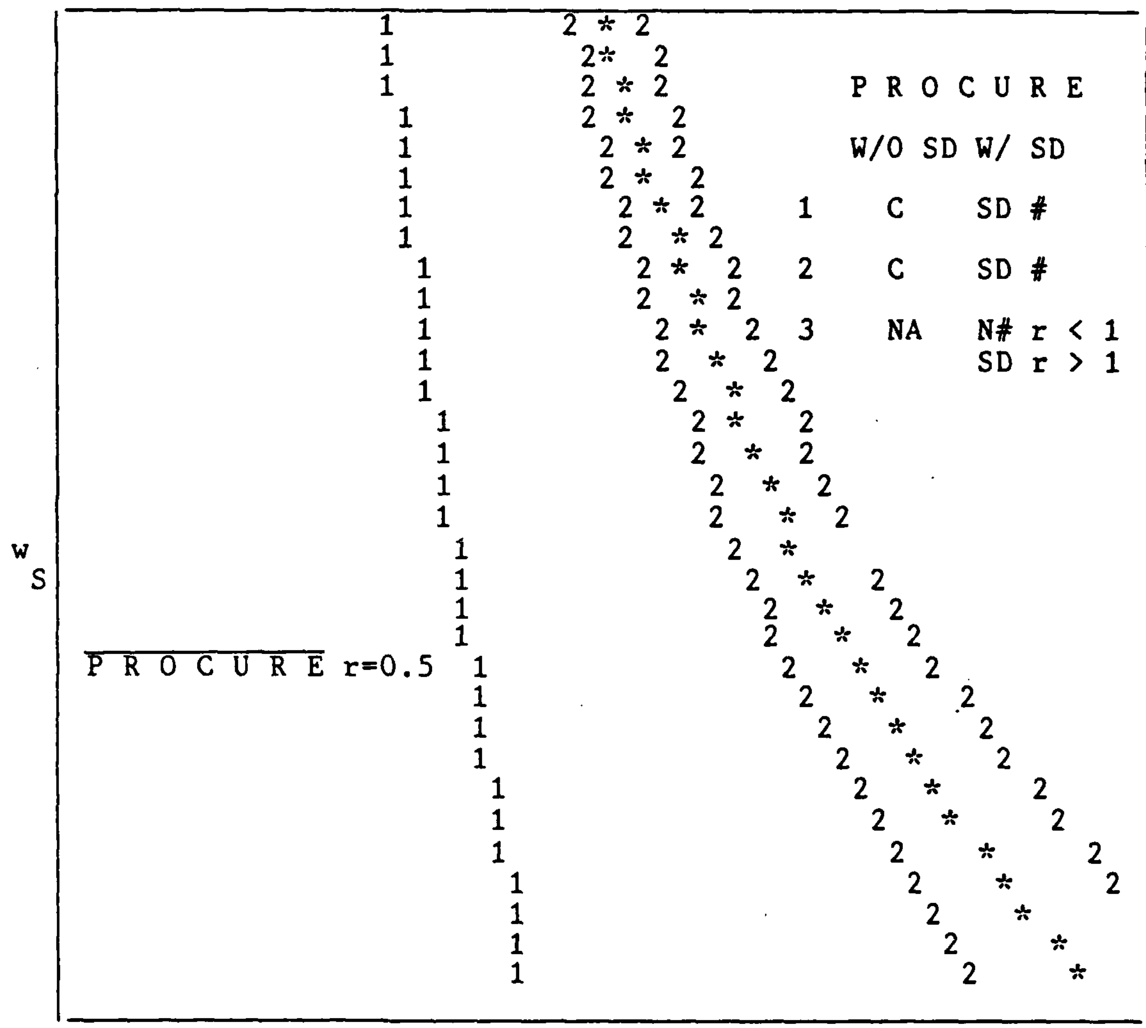
Figure 5.11 summarizes the results of the Stackelberg model when the national security value model does not depend on the defense industry value, i.e., $b = 1$. The procurement decisions and relative size of the incentives are the same as the previous model. The states have the same relative sensitivity to r as the previous model; however, for $r \geq 1.4$, the leader will always decide not to procure. (The value of r depends on the representative numbers we use.)

The results of our Stackelberg analysis provide insight into to the potential usefulness of a properly designed leader/follower approach as a transition strategy from state 1 to alternative states with lower nuclear weapon levels. First, the follower should be the country with the larger defense spending potential which incentivizes the leader not to procure. This incentive not to procure increases, if both countries believe that the follower also has the superior

S T A C K E L B E R G

MAX U_S^L

1 EACH COUNTRY'S DECISION r = 1.4



0 a 1

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Figure 5.11

weapons technology. Second, in our analysis, we assume bot[h] countries have perfect information about the other's arm[s] procurement and violation decisions. Clearly, informatio[n] about the other country's procurement decisions would b[e] important to both countries. However, if the follower ha[s] the smaller defense spending potential and poorer technolog[y] base, the follower has more potential risk due to agreemen[t] violations by the leader. Therefore, the follower should b[e] the country with the best information about the othe[r] country's decisions.

This analysis strongly suggests that the Soviet Unio[n] should be the leader and the United States should be th[e] follower in any leader/follower transition strategy. A[n] additional benefit of the U.S. in the follower role is tha[t] the blame for any resulting arms race will rest with th[e] leader and the American defense establishment might find i[t] relatively easy to obtain public support for weapon system[s] to respond to Soviet procurements. However, the U.S[.] defense establishment might perceive this strategy as risky because the Soviets might decrease their weapons.

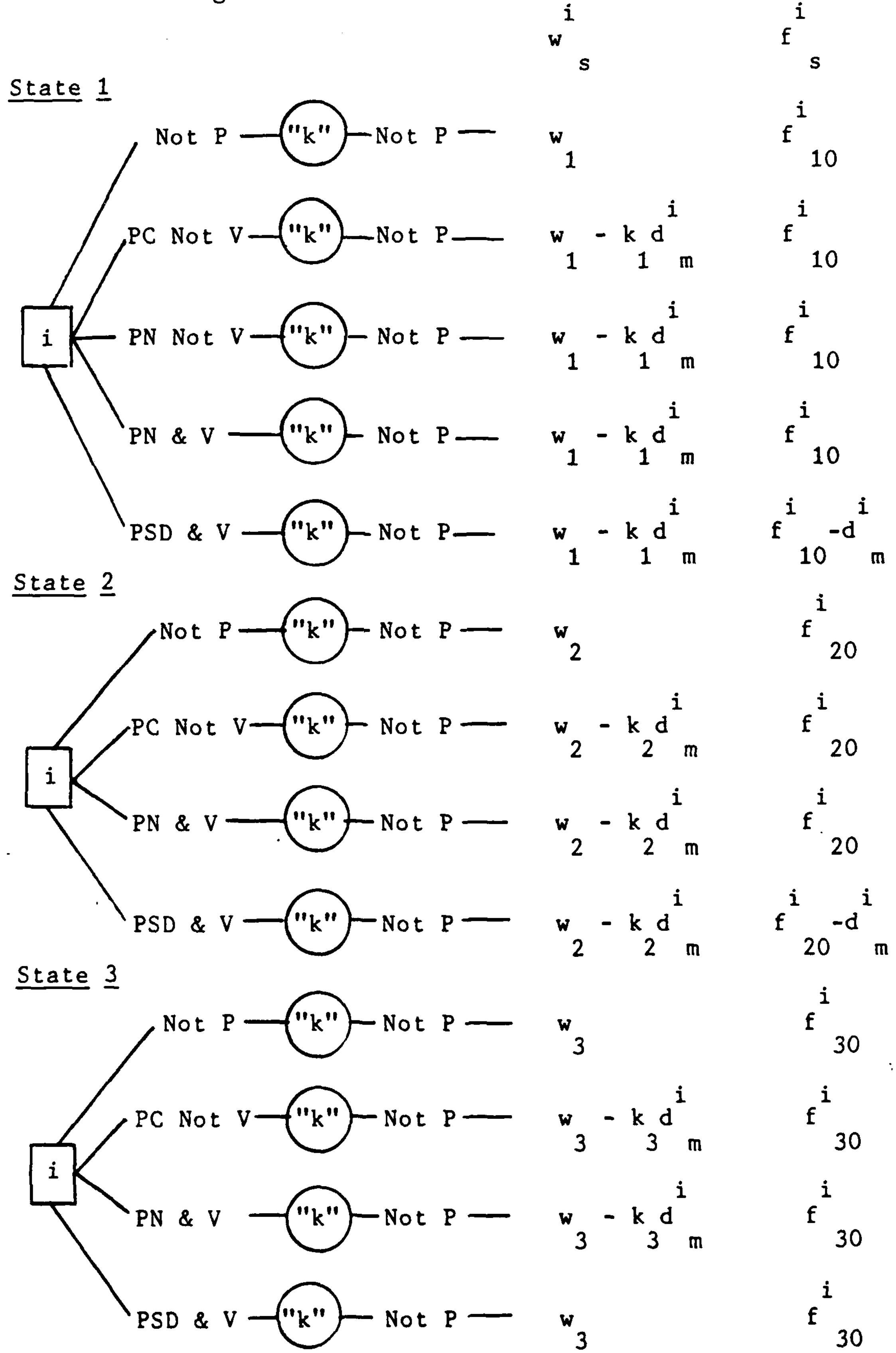
5.2.5 Control

Next, we analyze the effect on country i of the abilit[y] of control country k's arms procurement and contro[l] decisions. Clearly, with two superpowers it is ver[y] doubtful that one could completely control the arm[s] procurement and control decisions of the other. However[,] both superpowers have attempted to influence the arm[s] procurement and control decisions of the other superpower b[y] appealing to public opinion and/or threatening various arms procurement responses to the other's actions. Two recent examples are the Euromissiles and the current arguments about violations of arms control agreements. NATO's dual track decision of December 1979 was an attempt to dissuade the Soviet Union from further SS-20 procurements. To prevent the Pershing II/GLCM deployments, the Soviets appealed to public opinion and publicly and privately threatened NATO countries. Recently, the U.S. accused the Soviets of major arms control treaty violations (including SALT II which was never ratified by the Senate). The Soviets countered with a list of alleged American arms control treaty violations.

Although perfect control of the other superpower's arms procurement and control decisons is not realistic, the concept is analytically interesting because it provides insight into arms procurement and control decision-making in the three alternative states of the world by providing a limiting case.

The decision trees for our control analysis are shown in Figure 5.12. The notation "k" denotes that the decision of country k is controlled by country i. We are able to simplify the decision tree, since country "k's" do not procure alternative dominates country "k's" other alternatives because country i can only be worse off if country "k" procures.

Figure 5.12 CONTROL DECISION TREES



State 1

By comparing the national security value functions, W_1^i, for each alternative, we can draw two conclusions from the state 1 decision tree in Figure 5.12. First, country i is indifferent between procuring nuclear weapons and conventional forces. Second, the strategic defense procurement alternative dominates the other procurement alternatives.

With Strategic Defense

Country i will decide not to procure, if:

$$W_1^i \, [\text{ Not P} \mid \&_1 \,] < W_1^i \, [\text{ PSD} \mid \&_1 \,].$$

$\&_1$ is the state of information in the current state.

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_1 + k_1 \, (f_{10}^i - d_{max}^i) < g \,/\, a \, b$$

Using our initial conditions, we obtain:

$$b > \frac{1}{2 - a\,(\,w_1 + 3.49\,)}.$$

Otherwise, country i will procure strategic defense.

Without Strategic Defense

Country i will decide not to procure, if:

$$W_1^i \, [\text{ Not P} \mid \&_1 \,] < W_1^i \, [\text{ PC or N} \mid \&_1 \,].$$

When we substitute the values in the decision tree and use our initial conditions, we obtain:

$$b > \frac{1}{2 - a\,(\,3.5\,)}.$$

This equation results in approximately the same procurement regions as the previous case.

<u>State 2</u>

By comparing the national security value functions, W^i_2, *for each alternative,* we draw three conclusions from the state 2 decision tree in Figure 5.12. First, since controlled new nuclear weapons are not allowed in state 2, country i has one less alternative. Second, the decision-maker is indifferent between conventional forces and uncontrolled nuclear weapons. Third, the strategic defense procurement alternative dominates the other procurement alternatives.

<u>With Strategic Defense</u>

Country i will decide not to procure, if:

$$W^i_2\,[\text{ Not P } |\ \&_2\,] < W^i_2\,[\text{ PSD } |\ \&_2\,].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_2 + k_2\,(f^i_{20} - d^i_{max}) < g\,/\,a\,b.$$

Using our initial conditions, we obtain:

$$b > \frac{1}{2 - a\,(\,w_1 + 1.15\,)}.$$

Otherwise, country i will procure strategic defense.

Without Strategic Defense

Country i will decide not to procure, if:

$$W_2^i [\text{ Not P } | \ \&_2] < W_2^i [\text{ PC or PN \& Not V } | \ \&_2].$$

When we substitute the values in the decision tree and use our initial conditions, we obtain:

$$b > \frac{1}{2 - a(1.25)}.$$

State 3

By comparing the national security value functions, W_3^i, for each alternative, we can draw three conclusions from the decision tree for state 3 in Figure 5.12. First, since controlled new nuclear weapons are not allowed in state 3, the leader has the same alternatives as state 2. Second, the decision-maker is indifferent between conventional forces and uncontrolled nuclear weapons. Third, the conventional and uncontrolled nuclear alternatives dominate the strategic defense alternative.

Country i will decide not to procure, if:

$$W_3^i [\text{ Not P } | \ \&_3] < W_3^i [\text{ PC or PN \& Not V } | \ \&_3].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$b > \frac{1}{2 - 1.05\,a}.$$

Otherwise, country i will procure conventional or nuclear weapons.

Summary

The effects of control were analyzed by giving country i control over country k's decisions. For all of country i's alternatives in all states, country i would decide to have country k not procure. The results of the control analysis are summarized in Figures 5.13 and 5.14. Country i's incentive to procure is larger than with other equilibrium concepts and varies significantly with the state. State 1 has the largest incentive to procure, and state 3 has the least incentive to procure. As we have found in previous equilibrium concepts, the availability of strategic defense in states 1 and 2 creates an incentive to violate the arms control agreements; however, in state 3, country i never strictly prefers to violate the agreements.

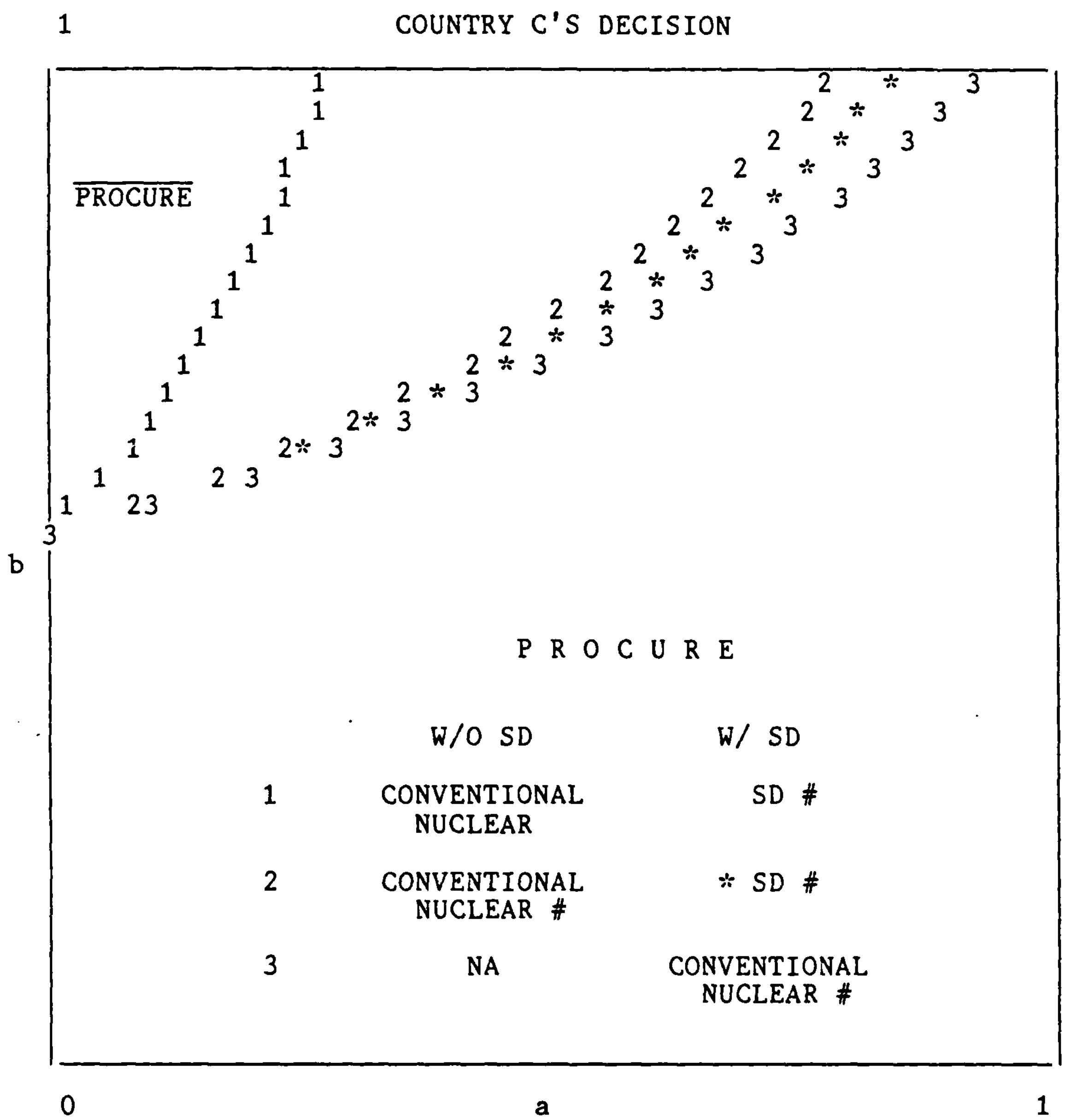
The intuitive reasons for these results are twofold. First, by procuring when country k does not procure, country i can reduce the probability of war and increase defense industry value. Second, by procuring strategic defense, country i can reduce the destruction should war occur. However, in state 3, country i does not procure strategic defense, since it does not reduce the probability of war or reduce the destruction should war occur; instead, country i procures conventional forces to reduce the probability of war and increase defense industry value.

5.2.6 Summary

We have developed and used our static deterministic model to analyze the arms procurement and control stability of the alternative states of the world, under cooperative

C O N T R O L

$$\text{MAX } W_S = W_S^C$$

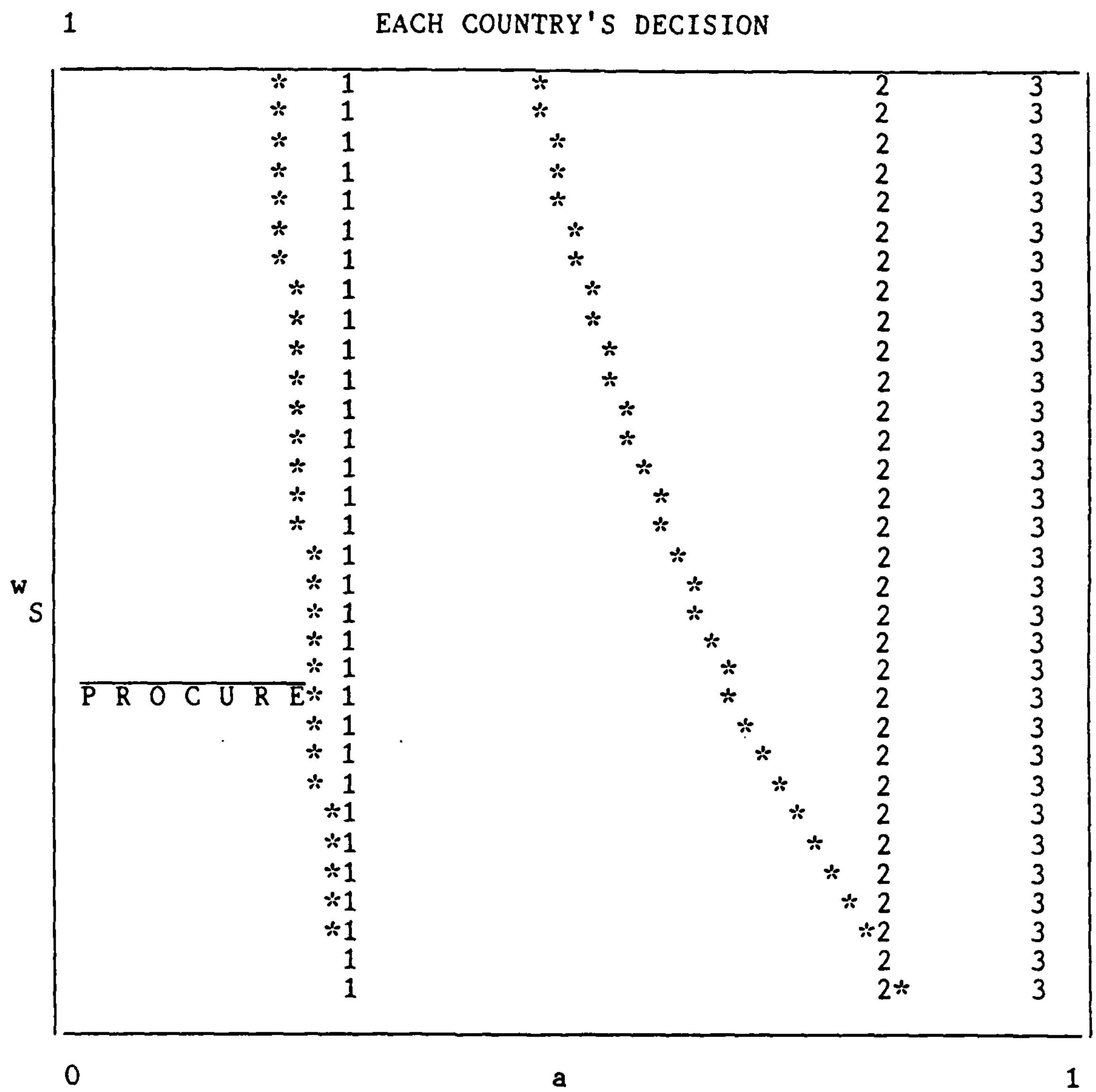


VIOLATION OF THE ARMS CONTROL AGREEMENTS

Figure 5.13

C O N T R O L

MAX U^{C}_{S}



VIOLATION OF THE ARMS CONTROL AGREEMENTS

Figure 5.14

P R O C U R E

	W/O SD	W/ SD
1	C N	* SD #
2	C N #	* SD #
3	NA	SD # N #

and noncooperative equilibrium assumptions. Our analysis began with the nation's value function composed of the value of the nation less the defense industry and the value of the defense industry. We subsequently removed the defense industry contribution to examine the effects on the arms procurement and control incentives. In this section, we summarize the major results of Section 5.2.

First, we used a collusion equilibrium concept to examine cooperation on the arms procurement and arms violation decisions of the two nations. In state 1 and 2, with strategic defense, it is never optimal for both nations to procure nuclear weapons; the decision-maker has a larger incentive to procure strategic defense, since it reduces the potential destruction should a war occur. If strategic defense is not available in states 1 and 2, the collusion decision-maker has an incentive to procure conventional forces, since the potential destruction is less per defense dollar expended than nuclear weapons. In state 3, both nations have an incentive to procure defense goods that do not increase the potential destruction, i.e., strategic defense or nuclear weapons. (The decision to procure nuclear weapons in state 3 is an arms control violation; however, it is "equivalent" to strategic defense, since, in our model with effective strategic defense, we assume a limited number of nuclear weapons will not increase the potential destruction in state 3 and we do not explicitly assign value to complying with the arms control agreements.)

If the collusion value model is used as a cardinal value function, state 3 is preferred to states 1 and 2, if the probabilities of war are of the same order of magnitude. The decision-maker's preference between states 1 and 2 depends on the relative levels of weapons and the relative probabilities of war.

Second, we used a Cournot-Nash equilibrium concept to examine noncooperative decision-making. As expected, noncooperative decision-making increases the incentive to procure weapons compared to cooperative decision-making. We find that it is never optimal to procure controlled nuclear weapons in any state. In states 1 and 2, the decision-maker has the largest incentive to procure strategic defense; but, if strategic defense is not available, he is indifferent between uncontrolled nuclear weapons and conventional forces. In state 3, the decision-maker is indifferent between procuring conventional or uncontrolled nuclear weapons; he prefers these over strategic defense, since strategic defense does not affect the probability of war in our state 3 model for w_s^i. Finally, we presented a typology for arms procurement and control stability solutions to the Cournot-Nash equilibrium concept (Table 5.1) and conceptually described how a decision-maker's ordinal preference ordering of these stability definitions could be used to compare the Cournot-Nash solutions for the three states. This typology of arms procurement and control definitions provides a useful analytical categorization of the possible outcomes of the superpowers' arms procurement and arms violation decisions.

Third, we used a Stackelberg equilibrium concept to analyze a very interesting form of limited cooperation. Country i was the leader, and country k was the follower in our analysis. We assumed that the follower has perfect information about the leader's decisions and agrees to procure the same types of weapons as the leader; and, we solved for the leader's optimal decision. The results are sensitive to the relative magnitude of each country's defense expenditures. (See equation 5.37.) If the leader knows that its maximum defense expenditure is greater (less) than the follower's, the larger the difference the greater the leader's incentive to procure increases (decreases). State 1 is the most sensitive to the relative defense expenditures, state 2 was less sensitive, and state 3 was very insensitive. State 1 is the most sensitive, since a change in the expected probability of war has the largest effect on the expected destruction. For each state, one or more alternatives is dominated. As we found in our Cournot-Nash analysis, the availability of strategic defense in states 1 and 2 creates an incentive to violate the arms control ageeements; however, there is no incentive to violate the arms control agreements in state 3. Finally, we concluded that the leader/follower approach has potential usefulness as a transition strategy from state 1 to an alternative with lower weapons levels.

Fourth, we analyzed perfect control; we assumed that country i had perfect control over country k's arms procurement and control decisions. We found that this concept resulted in the largest incentive to procure. Again, we found that the availability of strategic defense provided an incentive to violate the agreement in states 1 and 2.

Finally, we summarize the results of the analysis that do not depend in the equilibrium concept. If the decision-maker has a relatively higher value for the defense industry's interests than the interests of the country less the defense industry, he will procure. We found that the decision-maker was more sensitive to relative values (b vs 1-b) than to the opponent's arms procurement decisions. As expected, deletion of the defense industry's value from the nation's value function significantly decreases the incentive to procure in all four equilibrium concepts. For example, in collusion with b=1, there is no incentive to procure weapons at all.

As noted above, it is never optimal to procure controlled nuclear weapons (in state 1 and 2) since it increases the destruction both nations could suffer, does not reduce the probability of war (by our modeling assumption), and increases defense spending. This is a very interesting result, since controlled amounts of new nuclear weapons have been a central element of recent strategic arms control agreements, e.g. SALT II.

Uncontrolled nuclear and conventional forces are substitute public goods. With cooperative decision-making, conventional offense is preferred to nuclear offense because the damage for the dollar is less. However, with noncooperative decision-making, our decision-maker's model does not include damage to the opponent and considers each weapon type equally effective in reducing the probability of war; therefore, the decision-makers are indifferent between uncontrolled nuclear and conventional offense.

Finally, we summarize the results of our analysis of each state of the world, assuming approximately the same probability of war in all three states. State 1 has the most arms procurement stability and, because of the high level of nuclear weapons, is relatively insensitive to the opponent's arms control violations. State 2 is the most unstable, since it is the most sensitive to the opponent's arms control violations, because of the low nuclear weapons levels and the lack of strategic defense. State 3 provides the largest incentive not to procure weapons and, because of strategic defense, is not sensitive to arms control violations. However, the state 3 results rest on the effectiveness of the strategic defense capability. In addition, if the decision-makers perceive that the probability of war is reduced in state 3 (which is one major reason for considering it), it would be more stable.

5.3 Static Probalilistic Model

5.3.1 Introduction

In our probabilistic analysis, we use the normal decision analysis definitions of uncertainty and information. Uncertainty refers to our knowledge of the likelihood of the possible outcomes of a random variable. If we believe all outcomes are equally probable, uncertainty is the highest. Since the probability we assign to the outcomes depends on our knowledge, we can reduce the uncertainty by obtaining information about the likelihood of the outcomes. If some uncertainty still remains after receiving additional information, we have imperfect information. We have perfect information, if we are certain only one outcome will occur.

Uncertainty is a major issue in national security planning. The major justification for the use of worst-case analysis of the opponent's capabilities and intentions is the high risk to our national security of an assessment that underestimates the opponent's forces or relies on optimistic estimates of the opponent's intentions. Due to the information asymmetry described in Chapter 2, there is more uncertainty about the Soviet Union than about the United States.

Country i is uncertain about country k's arms procurement decisions and whether or not these new weapons violate the arms control agreements. This uncertainty poses risks for country i because of the security dilemma described in Chapter 2. Country k's arms procurement decisions that do not violate the arms control agreement can create incentives for country i to respond by procuring new weapons. A recent example of arms procurement instability is the Soviet decision to continue procuring the SS-20s above the number required to replace the SS-4s and SS-5s in Europe. NATO perceived this action as destabilizing and responded with the Pershing II/GLCM decision.

Uncertainty about arms control violations results in two risks. First, the short range risk that these possible violations could be militarily significant (major violation) exists, and, therefore, an immediate impact on national security could result. Second, the long range risk that, if these possible violations (minor violations) continue, and if country i does not respond, then they could become militarily significant. Part of the concern is the possibility that a lack of response to suspected violations may increase the incentives for further violations. Of course, with a high level of superpower suspicion and distrust, any violation may be politically significant.

We do not consider uncertainty about either country's values, but rather examine the effects of uncertainty on country i's arms procurement and arms violation incentives using the value model developed in Section 5.1. Since we do not develop a national security utility function, we do not examine the effects of uncertainty on risk preference.

5.3.2 Equilibrium Concept

We analyze the effects of uncertainty about country k's arms procurement decisions, including whether or not country k plans to violate the arms control agreements, on country i's incentives to procure weapons that do, or do not, violate the arms control agreements. Specifically, to analyze the alternative states of the world, we modify our static deterministic model to add probabalistic elements, and then we solve country i's decision problem using a Cournot-Nash equilibrium concept.

For each decision alternative of country k, we assess the probability of that decision and evaluate country i's value function based on worst-case assumptions about country k's actions (special case of Cournot-Nash). Then country i's expected value is the probability that country k makes that decision times country i's value for that decision. The best decision for country i is assumed to be the alternative with the highest expected value.

5.3.3 Uncertainty about Nuclear Weapon Procurement and Violation Decisions

Country i is uncertain about whether or not country k is violating the current arms control agreements. This violation by country k could result from clandestine nuclear weapons retained at the start of the arms control agreement or nuclear weapons secretly procured after the agreement was implemented. The following model random variables are of interest:

$\underline{x}^{k}_{s3}$ - opponent's existing uncontrolled nuclear weapons

$\underline{z}^{k}_{s1}$ - opponent's existing strategic defense

Country i is also uncertain about future arms procurement decisions. The following model random variables are of interest:

$\underline{x}^{k}_{s4}$ - opponent's new uncontrolled nuclear weapons

$\underline{y}^{k}_{s2}$ - opponent's new conventional offense

$\underline{z}^{k}_{s2}$ - opponent's new strategic defense

The uncertainty about the current and future nuclear weapons levels increases the uncertainty about the military technologies defined in Section 5.1. Each country is concerned about the effectiveness of both country's offensive and defensive weapons. Country i is uncertain about its own technology because of its inability to test weapon systems, especially nuclear weapon systems, in wartime conditions. There is even more uncertainty about the opponent's weapon system effectiveness due to the relative dearth of information.

Since country i's destruction should war occur, $\underline{f}^{i}_{s}$, is a function of country k's nuclear offense and the probability of war, $\underline{w}^{i}_{s}$, which is a function of the opponent's new procurement decisions, both variables become random variables in our probabilistic model.

We could think of each of these variables as continuous or discrete random variables. If we consider these variables continuous, we could assign a probability density over the range of possible outcomes of the variables. If we consider the variables as discrete random variables, we could assign probabilities to the following outcomes for each of the variables: no violations, minor violations, and major violations.

In our analysis, we focus on the uncertainty about new procurement and violation decisions. We incorporate uncertainty in our model by considering three possible alternatives available to each country: do not procure, procure weapons that do not violate the arms control agreements, and procure weapons that do violate the arms control agreements. For each arms control violation decision, we assume country k procures nuclear weapons. Country i assigns the following probabilities to the alternatives of country k:

probability country k will not procure = 1 - p - v

probability country k will procure but not violate = p

probability country k will procure and violate = v.

5.4 Noncooperative Decision-making with Uncertainty

5.4.1 Cournot-Nash

In this section, we analyze the effects of uncertainty on country i's arms procurement and control decision-making for each state of the world. Since effective strategic defense may or may not exist for states 1 and 2, we consider two cases for each of these states. In the "with strategic defense" case, we assume that effective strategic defenses exist; however, strategic defense is still a violation in states 1 and 2. In the "without strategic defense" case, we assume that effective strategic defenses do not exist.

State 1

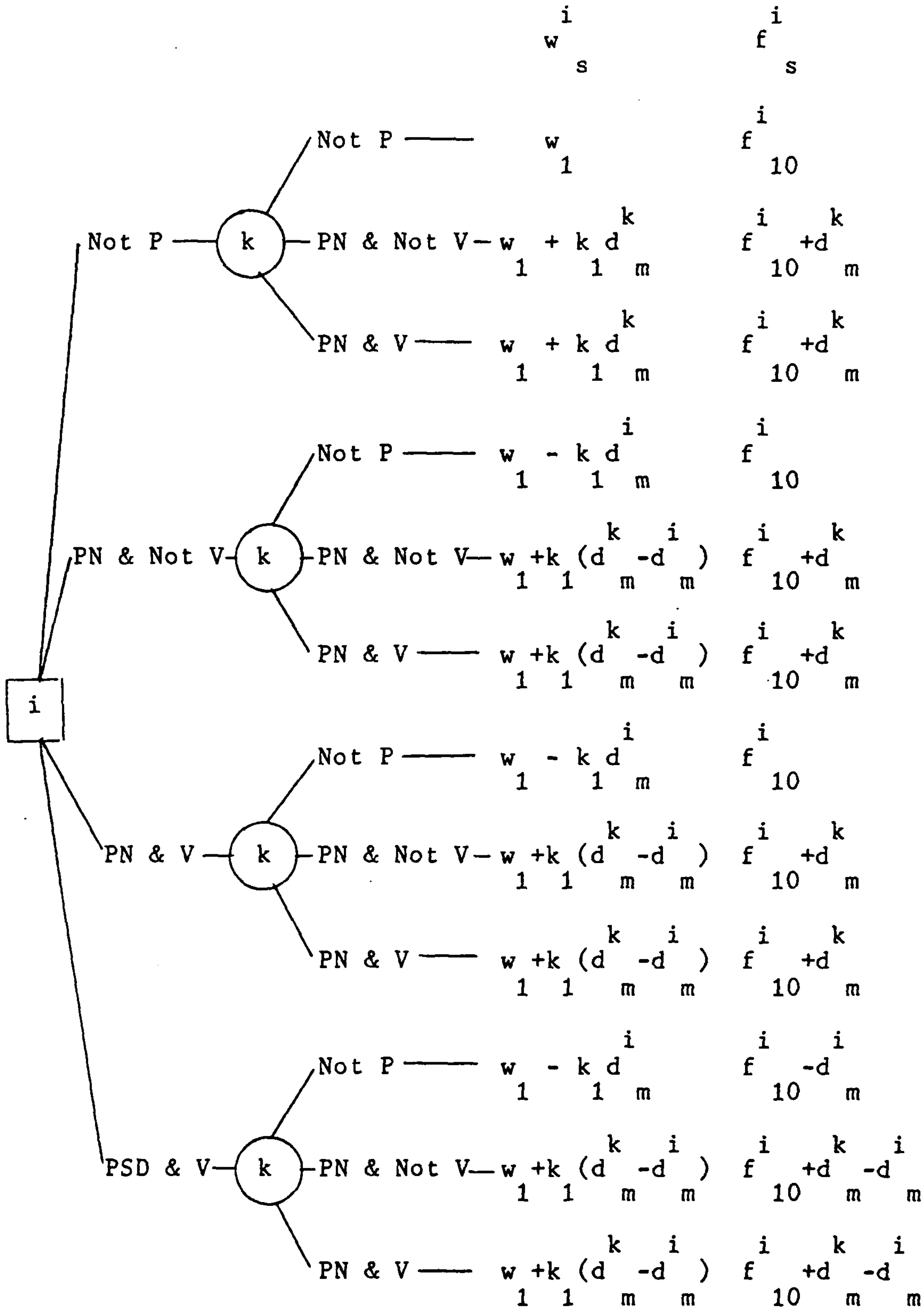
The state 1 decision tree for our probabilistic analysis is shown in Figure 5.15. To simplify the analysis, we do not include the alternative of procuring conventional forces since conventional and nuclear weapons are substitute goods in state 1.

By comparing the expected national security value functions, $\underline{W}^i_1$, for each of country i's alternatives, we draw two conclusions. First, the decision-maker is indifferent between the procure nuclear weapons and violate alternative and the procure nuclear weapons and do not violate alternative, since

$$\underline{W}^i_1 \,[\text{ PN \& Not V} \mid \&_1] = \underline{W}^i_1 \,[\text{ PN \& V} \mid \&_1].$$

Second, the procure strategic defense and violate alternative dominates the procure nuclear alternatives,

Figure 5.15 STATE 1 DECISION TREE WITH UNCERTAINTY



since

$$\underline{W}^{i}_{1}\,[\,PSD\ \&\ V\mid \&_{1}\,] < \underline{W}^{i}_{1}\,[\,PN\mid \&_{1}\,].$$

<u>With Strategic Defense</u>

Country i will not procure, if:

$$\underline{W}^{i}_{1}\,[\,Not\ P\mid \&_{1}\,] < \underline{W}^{i}_{1}\,[\,PSD\ \&\ V\mid \&_{1}\,].$$

When we substitute the values in the decision tree
simplify, the condition becomes:

$$\underline{w}^{i}_{1} + k_{1}\,\underline{f}^{i}_{1} < g / a\ b.$$

Otherwise, country i will procure strategic defense.

<u>Without Strategic Defense</u>

Country i will not procure, if:

$$\underline{W}^{i}_{1}\,[\,Not\ P\mid \&_{1}\,] < \underline{W}^{i}_{1}\,[\,PN\mid \&_{1}\,].$$

When we substitute the values in the decision tree
simplify, we obtain:

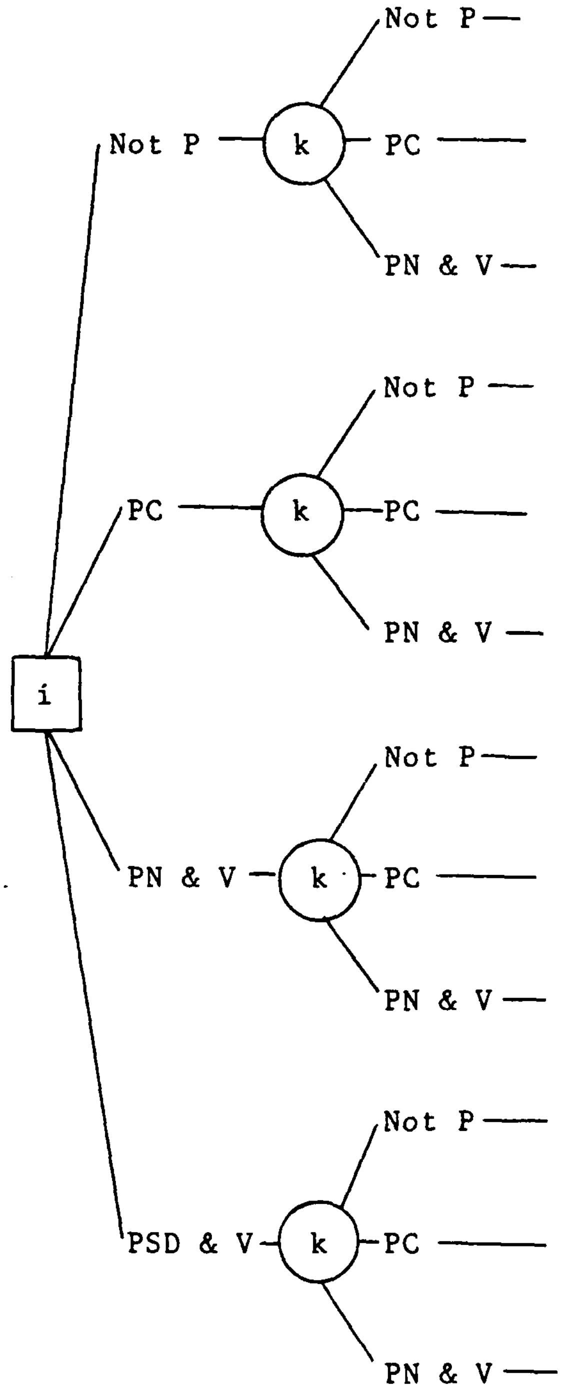
$$k_{1}\,\underline{f}^{i}_{1} < g / a\ b.$$

If $\underline{w}^{i}_{s}$ is small, this equation results in approximately
same procurement regions as the previous case.

<u>State 2</u>

The state 2 decision tree for our probabilis
analysis is shown in Figure 5.16. By comparing the expec
national security value functions, $\underline{W}^{i}_{2}$, for each of coun
i's alternatives, we can draw two conclusions. First,

Figure 5.16 STATE 2 DECISION TREE WITH UNCERTAINTY



Decision i	Outcome k	w^i_s	f^i_s
Not P	Not P	w_2	f^i_{20}
Not P	PC	$w_2 + k_2 d^k_m$	$f^i_{20} + cd^k_m$
Not P	PN & V	$w_2 + k_2 d^k_m$	$f^i_{20} + d^k_m$
PC	Not P	$w_2 - k_2 d^i_m$	f^i_{20}
PC	PC	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + cd^k_m$
PC	PN & V	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + d^k_m$
PN & V	Not P	$w_2 - k_2 d^i_m$	f^i_{20}
PN & V	PC	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + cd^k_m$
PN & V	PN & V	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + d^k_m$
PSD & V	Not P	$w_2 - k_2 d^i_m$	$f^i_{20} - d^i_m$
PSD & V	PC	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + cd^k_m - d^i_m$
PSD & V	PN & V	$w_2 + k_2 (d^k_m - d^i_m)$	$f^i_{20} + d^k_m - d^i_m$

decision-maker is indifferent between the procure nuclear weapons and violate alternative and the procure nuclear weapons and do not violate alternative, since

$$\underline{W}^{i}_{2} [PN \& Not V \mid \&_{2}] = \underline{W}^{i}_{2} [PN \& V \mid \&_{2}].$$

Second, the procure strategic defense and violate alternative dominates the procure nuclear alternatives since

$$\underline{W}^{i}_{2} [PSD \& V \mid \&_{2}] < \underline{W}^{i}_{2} [PN \mid \&_{2}].$$

<u>With Strategic Defense</u>

Country i will not procure, if:

$$\underline{W}^{i}_{2} [Not P \mid \&_{2}] < \underline{W}^{i}_{2} [PSD \& V \mid \&_{2}].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$\underline{w}^{i}_{2} + k_{2} \underline{f}^{i}_{2} < g / a b.$$

Otherwise, country i will procure strategic defense.

<u>Without Strategic Defense</u>

Country i will not procure, if:

$$\underline{W}^{i}_{2} [Not P \mid \&_{2}] < \underline{W}^{i}_{2} [PN \mid \&_{2}].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_{2} \underline{f}^{i}_{2} < g / a b.$$

<u>State 3</u>

The state 3 decision tree for our probabilistic analysis is shown in Figure 5.17. By comparing the expected national security value functions, $\underline{W}^i_3$, for each of country i's alternatives, we draw two conclusions. The decision-maker is indifferent between the procure conventional forces alternative and the procure nuclear weapons and violate alternative, since

$$\underline{W}^i_3 [\ PC \mid \&_3\ ] = \underline{W}^i_3 [\ PN \ \&\ V \mid \&_3\ ].$$

Second, the procure strategic defense alternative is dominated by the other procurement alternatives, since

$$\underline{W}^i_3 [\ PN \ \&\ V \text{ or } PC \mid \&_3\ ] < \underline{W}^i_3 [\ PSD \mid \&_3\ ].$$

Country i will not procure, if:

$$\underline{W}^i_3 [\ \text{Not } P \mid \&_3\ ] < \underline{W}^i_3 [\ PN \ \&\ V \text{ or } PC \mid \&_3\ ].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$k_3 \underline{f}^i_3 < g \ / \ a \ b.$$

Otherwise, country i will procure conventional forces or uncontrolled nuclear weapons.

<u>Uncertainty about Arms Procurement Decisions Only</u>

Next, we examine the special case that country i believes country k will not violate the arms ontrol agreements; however, country i is uncertain whether or not country k will procure. We consider the effects of uncertainty on the maximum potential destruction country i

Figure 5.17 STATE 3 DECISION TREE WITH UNCERTAINTY

i	k	w^i_s	f^i_s
Not P	Not P	w_3	f^i_{30}
	PC	$w_3 + k_3 d^k_m$	$f^i_{30} + cd^k_m$
	PN & V	$w_3 + k_3 d^k_m$	$f^i_{30} + d^k_m$
PC	Not P	$w_3 - k_3 d^i_m$	f^i_{30}
	PC	$w_3 + k_3 (d^k_m - d^i_m)$	$f^i_{30} + cd^k_m$
	PN & V	$w_3 + k_3 (d^k_m - d^i_m)$	$f^i_{30} + d^k_m$
PN & V	Not P	$w_3 - k_3 d^i_m$	f^i_{30}
	PC	$w_3 + k_3 (d^k_m - d^i_m)$	$f^i_{30} + cd^k_m$
	PN & V	$w_3 + k_3 (d^k_m - d^i_m)$	$f^i_{30} + d^k_m$
PSD	Not P	w_3	f^i_{30}
	PC	$w_3 + k_3 d^k_m$	$f^i_{30} + cd^k_m$
	PN & V	$w_3 + k_3 d^k_m$	$f^i_{30} + d^k_m$

AD-A160 673 LARGE BILATERAL REDUCTIONS IN SUPERPOWER NUCLEAR WEAPONS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH G S PARNELL JUL 85 AFIT/CI/NR-85-104D

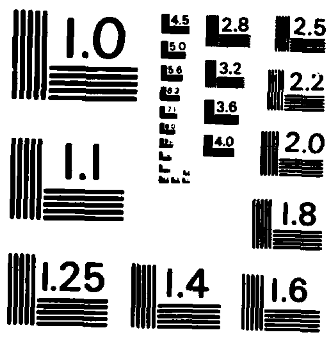
3/3

UNCLASSIFIED F/G 5/4 NL

END

FILMED

DTIC


1.0
4.5
5.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

could suffer in each state (assuming country i does not procure strategic defense):

$$\underline{f}^i_1 = f^i_{10} + (p + v) d^k_{max} \tag{5.37}$$

$$\underline{f}^i_2 = f^i_{20} + (p c + v) d^k_{max} \tag{5.38}$$

$$\underline{f}^i_3 = f^i_{30} + p c d^k_{max} \tag{5.39}$$

The probability of violation does not effect our state 3 model, because we assume effective strategic defense. When v = 0, the above equations become:

$$\underline{f}^i_1 = f^i_{10} + p d^k_{max}$$

$$\underline{f}^i_2 = f^i_{20} + p c d^k_{max}$$

$$\underline{f}^i_3 = f^i_{30} + p c d^k_{max}$$

In state 1, the increase in potential destruction is not large since $f^i_{10} >> d^i_{max}$. If country k were to procure conventional forces, the change would even be smaller. In state 2, the increase in incentive is not large, if $f^i_{20} >> c\ d^i_{max}$. The increase in state 3 is a larger percentage increase, since $f^i_{30} < f^i_{20}$.

Uncertainty about Arms Control Agreement Violations Only

Next, we consider the special case that country i believes that country k will violate the agreements, if it procures. With p = 0, equations (5.37), (5.38), and (5.39) become:

$$\underline{f}^i_1 = f^i_{10} + v\, d^k_{max}$$

$$\underline{f}^i_2 = f^i_{20} + v\, d^k_{max}$$

$$\underline{f}^i_3 = f^i_{30}$$

In state 1, the increase in potential destruction is not large since $f^i_{10} >> d^i_{max}$. In state 2, the increase in incentive depends on the relative magnitude of f^i_{20} and d^i_{max}. Effective strategic defense in state 3 results in no increase in the incentive to violate the agreements. Without strategic defense, the violation would be a larger percentage increase since $f^i_{30} < f^i_{20}$.

5.4.2 <u>The Effects of Uncertainty</u>

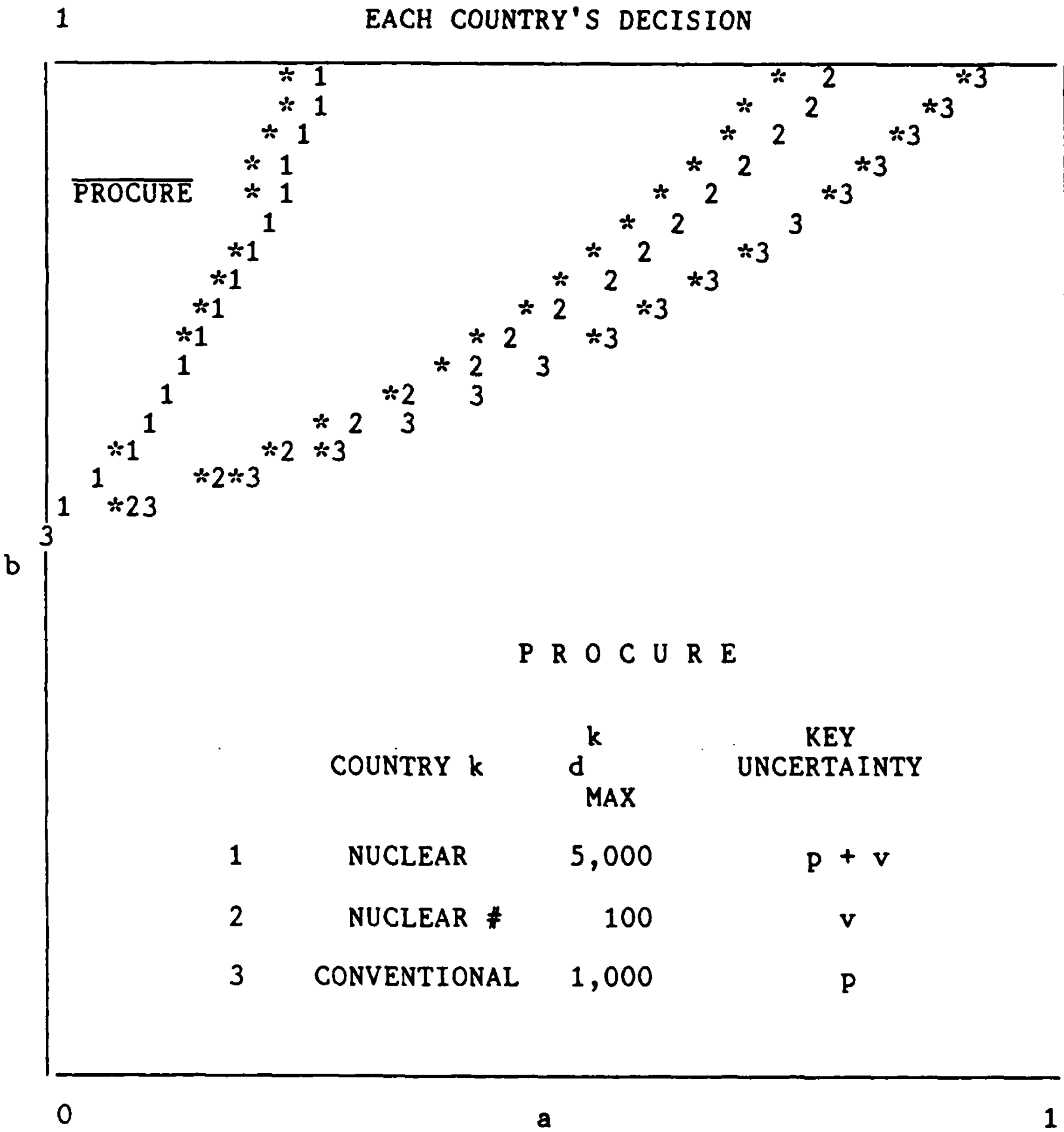
In the previous section, we analyzed the effects of uncertainty on the incentives to procure weapons that do and do not violate the arms control agreements in the alternative states of the world. The results of the uncertainty analysis are summarized in Figures 5.18 and 5.19.

Uncertainty about country k's nuclear weapons procurement and violation decisions increases country i's incentive to procure weapons. The inequalities defining the decision ranges are of the same form but the "destruction should war occur" variable is replaced by the corresponding random variable. Depending on the paramenter values, the p = PROBABILITY COUNTRY k PROCURES AND DOES NOT VIOLATE

v = PROBABILITY COUNTRY k PROCURES AND VIOLATES

1-p-v = PROBABILITY COUNTRY k DOES NOT PROCURE

EACH COUNTRY'S DECISION



P R O C U R E

	COUNTRY k	d^k_{MAX}	KEY UNCERTAINTY
1	NUCLEAR	5,000	p + v
2	NUCLEAR #	100	v
3	CONVENTIONAL	1,000	p

VIOLATION OF THE ARMS CONTROL AGREEMENTS

Figure 5.18

U N C E R T A I N T Y   A N D   I N F O R M A T I O N

p = PROBABILITY COUNTRY k PROCURES AND DOES NOT VIOLATE

v = PROBABILITY COUNTRY k PROCURES AND VIOLATES

1-p-v = PROBABILITY COUNTRY k DOES NOT PROCURE

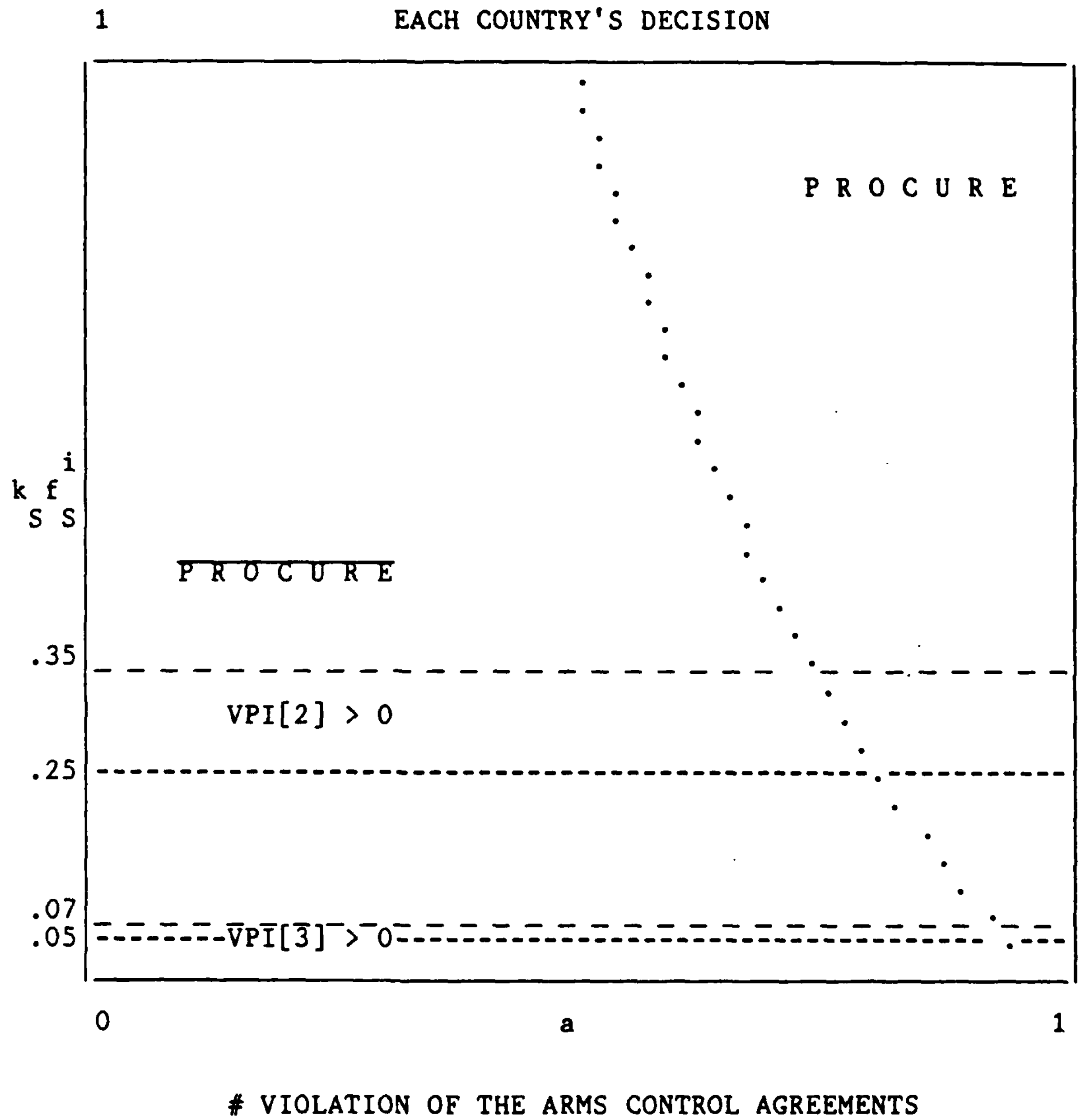


Figure 5.19

decision-maker may prefer not to procure or be indifferent between procuring and not violating and procuring and violating the arms control agreements. The decision-maker never strictly prefers to violate the arms control agreement.

The effect of uncertainty is strongly dependent on the alternative state of the world. In state 1, the effect of uncertainty is small since the nuclear weapons quantities are very large relative to the worst-case action by country k and, from equation (5.37), the expected destruction depends on the sum of the probabilities of procurement without violation (p) and procurement with violation (v) and not the relative magnitudes of p and v. Therefore, country i does not need to assess the individual probabilities and can hedge against arms procurement and violation uncertainty by procuring uncontrolled nuclear weapons. If country i believes country k will procure conventional forces, the expected destruction, and, therefore, the effect of uncertainty, is less. However, the expected destruction depends on the relative magnitudes of p and v since the potential destruction would increase by (c p + v) times the maximum defense spending.

Uncertainty in state 2 increases the incentive to procure. The magnitude of the increase depends on p and v; from equation (5.38), v is more critical since nuclear weapons are more destructive than conventional forces.

State 3 has strategic defense; therefore, uncertainty about violations does not increase the incentive to procure, and the expected destruction depends only on p. However, if we are certain country k is not violating the agreement, uncertainty about conventional forces procurement decisions, p, causes the largest percentage increase in the incentive to procure in state 3.

As we saw in Section 5.2, there is an incentive to procure strategic defense in states 1 and 2. Uncertainty about country k's decisions increases this incentive to violate the arms control agreements.

5.5 The Effects of Information

5.5.1 Introduction

Next, we analyze the value of information and the effects of information on the alternative states of the world. We begin our analysis by determining country i's value of information on country k's arms procurement and violation decisions. We then use the results of this analysis to examine the impact of information on country i's weapon system procurement decisions in each state.

5.5.2 The Value of Perfect Information about Procurement and Violation Decisions

Next, we examine perfect information about country k's arms procurement and violation decisions. The following existing defense goods could be considered random variables:

$$\underline{x}_{s1}, \ \underline{x}^{k}_{s3}, \ \underline{y}^{k}_{s1}, \text{ and } \underline{z}^{k}_{s1}.$$

However, as in Section 5.4, we assume perfect information on the past procurements and evaluate the effects of uncertainty about future defense goods; therefore, the following random variables are of interest:

$$\underline{x}^{k}_{s4}, \ \underline{y}^{k}_{s2}, \text{ and } \underline{z}^{k}_{s2}.$$

We use the normal decision analysis approach to calculate the value of perfect information (VPI). First, we assume perfect information on country k's possible arms procurement and violation decisons. Second, we solve for country i's optimum decision for each of country k's possible decisions. Since strategic defense is not allowed in states 1 and 2, we consider two cases for each of these states. Third, the expected value of perfect information (EVPI) is then the sum of the probability country k will make each decision times country i's optimum value given that decision. Finally, country i's VPI is the difference between the expected value (EV) and the EVPI.

As in Section 5.4, we consider two cases for states 1 and 2: with effective strategic defense and without effective defense. (See Section 5.4.1)

<u>State 1</u>

The state 1 decision tree for our value of perfect information analysis is shown in Figure 5.20. To simplify the analysis, we do not include the conventional force procurement alternative since conventional and nuclear weapons are substitute goods in state 1.

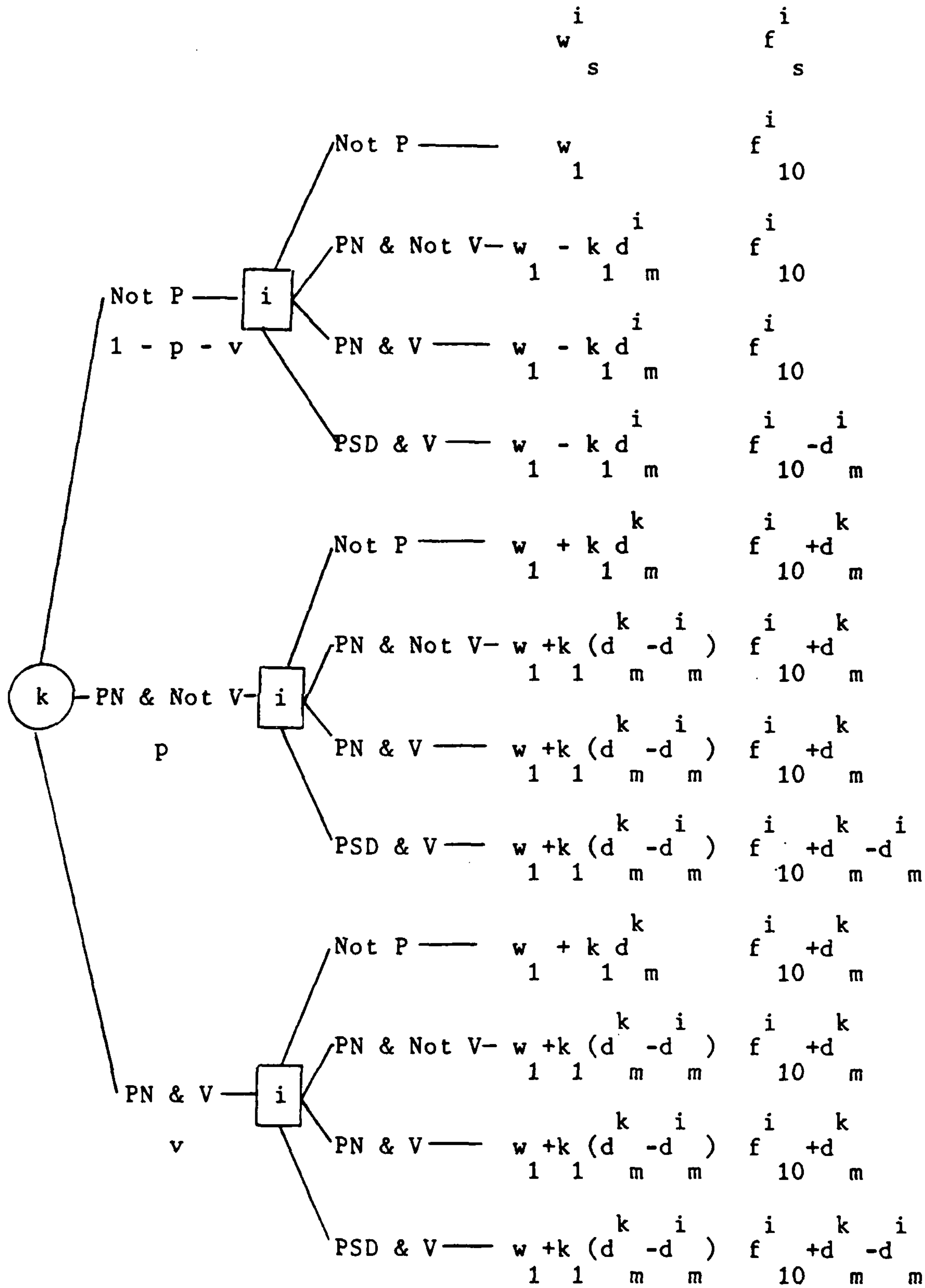
By maximumizing country i's national security value functions, W_1^i, for each of country k's possible alternatives, we draw two conclusions. First, the decision-maker is indifferent between the procure nuclear weapons and violate alternative and the procure nuclear weapons and do not violate alternative, since

$$W_1^i [\text{ PN \& Not V} \mid \&_1] = W_1^i [\text{ PN \& V} \mid \&_1].$$

Second, the procure strategic defense and violate alternative dominates the procure nuclear alternatives, since

$$W_1^i [\text{ PSD \& V} \mid \&_1] < W_1^i [\text{ PN} \mid \&_1].$$

Figure 5.20 STATE 1 VALUE OF PERFECT INFORMATION



With Strategic Defense

When country k does not procure, country i will not procure, if:

$$W^{i}_{1} [\text{ Not P} \mid \&_{1}] < W^{i}_{1} [\text{ PSD \& V} \mid \&_{1}].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_{1} + k_{1} (f^{i}_{10} - d^{i}_{max}) < g / a\, b.$$

Otherwise, country i will procure strategic defense.

When country k procures, country i will not procure, if:

$$W^{i}_{1} [\text{ Not P} \mid \&_{1}] < W^{i}_{1} [\text{ PSD \& V} \mid \&_{1}].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_{1} + k_{1} (f^{i}_{10} - d^{i}_{max} + 2\, d^{k}_{max}) < g / a\, b.$$

Otherwise, country i will procure strategic defense,

The VPI calculations are performed as follows:

$$VPI (\&_{1}) = EV (\&_{1}) - EVPI (\&_{1})$$

The expression g/ab is the relative value of defense budget versus expected destruction. The results are that VPI > 0 only in the following range of relative values:

$$w_{1} + k_{1} (f^{i}_{10} - d^{i}_{max}) < g / a\, b < w_{1} + k_{1} (f^{i}_{10} - d^{i}_{max} + 2\, d^{k}_{max})$$

The magnitude of this range of relative values is $2\, k_1\, d^k_{max}$. Furthermore, based on the representative numbers used in Section 5.2.3, we know that

$$2\, k_1\, d^k_{max} << f^i_{10}.$$

Without Strategic Defense

If country k does not procure, country i will not procure, if:

$$W^i_1 [\text{ Not P} \mid \&_1] < W^i_1 [\text{ PN} \mid \&_1].$$

When we substitute the values in the decision tree and simplify, the conditions are:

$$k_1\, f^i_{10} < g / a\, b.$$

If country k procures, country i will not procure, if:

$$W^i_1 [\text{ Not P} \mid \&_1] < W^i_1 [\text{ PN} \mid \&_1].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_1\, (f^i_{10} + d^k_{max}) < g / a\, b.$$

Otherwise, country i will procure nuclear weapons.

When we perform the VPI calculations for state 1 without strategic defense, the results are that VPI > 0 only in the following range of relative values:

$$k_1 f^i_{10} < g / a\, b < k_1 (f^i_{10} + d^k_{max})$$

The magnitude of this range of the relative value of defense budget versus expected destruction is $k_1 d^k_{max}$; one half the range of relative values we found in the case with strategic defense. Therefore, without strategic defense, information is likely to have less value.

State 2

The state 2 decision tree for our value of perfect information analysis is shown in Figure 5.21. By maximumizing country i's national security value functions, W^i_2, for each of country k's possible alternatives, we draw two conclusions. First, for each of country k's alternatives, country i is indifferent between its procure nuclear weapons and violate alternative and its procure conventional forces and do not violate alternative, since

$$W^i_2 [PC \ \& \ Not\ V \mid \&_2] = W^i_2 [PN \ \& \ V \mid \&_2].$$

Second, the procure strategic defense and violate alternative dominates the other procurement alternatives, since

$$W^i_2 [PSD \ \& \ V \mid \&_2] < W^i_2 [PN \ \& \ V \text{ or } PC \ \& \ Not\ V \mid \&_2].$$

With Strategic Defense

When country k does not procure, country i will not procure, if:

$$W^i_2 [Not\ P \mid \&_2] < W^i_2 [PSD \ \& \ V \mid \&_2].$$

When we substitute the values in the decision tree and

Figure 5.21 STATE 2 VALUE OF PERFECT INFORMATION

k	i	w_s^i	f_s^i
Not P ($1 - p - v$)	Not P	w_2	f_{20}^i
	PC & Not V	$w_2 - k_2 d_m^i$	f_{20}^i
	PN & V	$w_2 - k_2 d_m^i$	f_{20}^i
	PSD & V	$w_2 - k_2 d_m^i$	$f_{20}^i - d_m^i$
PC & Not V (p)	Not P	$w_2 + k_2 d_m^k$	$f_{20}^i + c d_m^k$
	PC & Not V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + c d_m^k$
	PN & V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + c d_m^k$
	PSD & V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + c d_m^k - d_m^i$
PN & V (v)	Not P	$w_2 + k_2 d_m^k$	$f_{20}^i + d_m^k$
	PC & Not V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + d_m^k$
	PN & V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + d_m^k$
	PSD & V	$w_2 + k_2 (d_m^k - d_m^i)$	$f_{20}^i + d_m^k - d_m^i$

simplify, the condition becomes:

$$w_2 + k_2 (f^i_{20} - d^i_{max}) < g / a\ b.$$

Otherwise, country i will procure strategic defense.

When country k procures conventional forces, country i will not procure, if:

$$W^i_2 [\text{ Not P } | \&_2] < W^i_2 [\text{ PSD \& V} | \&_2].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_2 + k_2 [f^i_{20} - d^i_{max} + (1 + c) d^k_{max}] < g / a\ b.$$

Otherwise, country i will procure strategic defense,

When country k procures nuclear weapons, country i will not procure, if:

$$W^i_2 [\text{ Not P } | \&_2] < W^i_2 [\text{ PSD \& V} | \&_2].$$

When we substitute the values in the decision tree and simplify, the condition becomes:

$$w_2 + k_2 (f^i_{20} - d^i_{max} + 2\, d^k_{max}) < g / a\ b.$$

Otherwise, country i will procure strategic defense,

The VPI calculations are performed as follows:

$$\text{VPI } (\&_2) = \text{EV } (\&_2) - \text{EVPI } (\&_2)$$

The results are that VPI > 0 only in the following range of the relative value of defense spending versus expected destruction:

$$w_2 + k_2 (f^i_2 - d^i_{max}) < g / a b < w_2 + k_2 (f^i_1 - d^i_{max} + 2 d^i_{max})$$

The magnitude of this range of relative values is $2\, k_2\, d^k_{max}$.

<u>Without Strategic Defense</u>

If country k does not procure, country i will not procure, if:

$$W^i_2 [\text{ Not P} \mid \&_2] < W^i_2 [\text{ PN} \mid \&_2].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_2\, f^i_{20} < g / a b.$$

If country k procures, country i will not procure if:

$$W^i_2 [\text{ Not P} \mid \&_2] < W^i_2 [\text{ PN} \mid \&_2].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_2 (f^i_{20} + d^i_{max}) < g / a b.$$

Otherwise, country i will procure conventional or nuclear weapons.

When we perform the VPI calculations for state 1 without strategic defense, the results are that VPI > 0 only in the following range of the relative value of defense spending versus expected destruction:

$$k_2\, f^i_{20} < g / a b < k_2 (f^i_{20} + d^k_{max}).$$

The magnitude of this range of relative values is $k\, d_{2\,max}^{k}$. As we found in state 1, with strategic defense, perfect information has positive value over twice the range of relative values compared to without strategic defense.

State 3

The state 3 decision tree for our value of perfect information analysis is shown in Figure 5.22. By maximumizing country i's national security value functions, W_3^i, for each of country k's possible alternatives, we draw two conclusions. First, for each of country k's alternatives, country i is indifferent between its nuclear weapons and violate alternative and its procure conventional forces and do not violate alternative, since

$$W_3^i\,[\text{ PC \& Not V } | \text{ \&}_3\,] = W_3^i\,[\text{ PN \& V } | \text{ \&}_3\,].$$

Second, the procure strategic defense and violate alternative is dominated by the other procurement alternatives, since

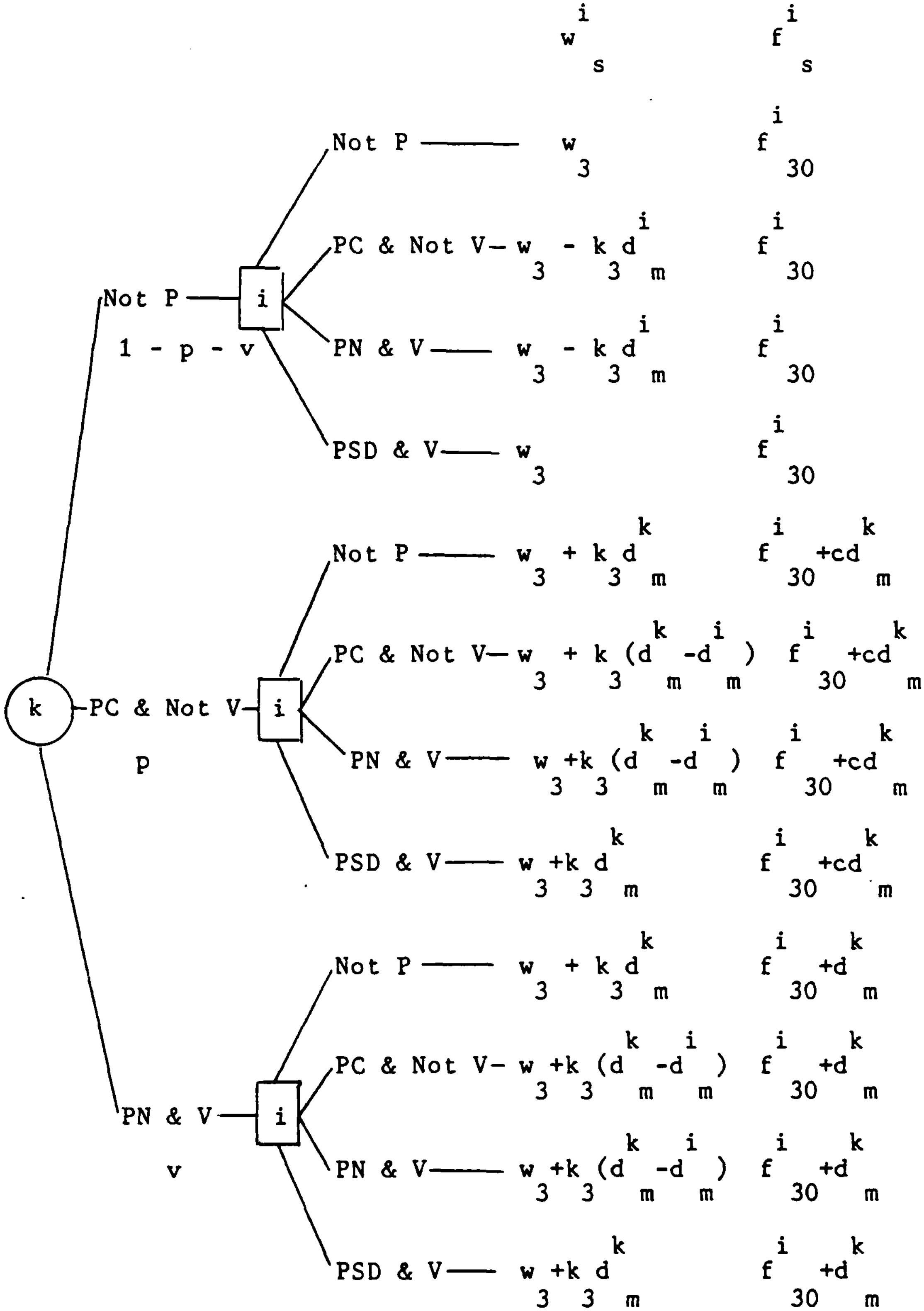
$$W_3^i\,[\text{ PN \& V or PC \& Not V } | \text{ \&}_3\,] < W_3^i\,[\text{ PSD \& V } | \text{ \&}_3\,].$$

If country k does not procure, country i will not procure, if:

$$W_3^i\,[\text{ Not P } | \text{ \&}_3\,] < W_3^i\,[\text{ PN } | \text{ \&}_3\,].$$

When we substitute the values in the decision tree and simplify, we obtain:

Figure 5.22 STATE 3 VALUE OF PERFECT INFORMATION



$$k_3 f^i_{30} < g / a\ b.$$

If country k procures conventional forces, country i will not procure, if:

$$W^i_3 [\text{ Not P} \mid \&_3] < W^i_3 [\text{ PN \& V or PC} \mid \&_3].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_3 (f^i_{30} + c\ d^i_{max}) < g / a\ b.$$

Otherwise, country i will procure conventional or nuclear weapons.

If country k procures nuclear forces, country i will not procure, if:

$$W^i_3 [\text{ Not P} \mid \&_3] < W^i_3 [\text{ PN \& V or PC} \mid \&_3].$$

When we substitute the values in the decision tree and simplify, we obtain:

$$k_3 (f^i_{30} + d^i_{max}) < g / a\ b.$$

Otherwise, country i will procure conventional or nuclear weapons.

When we perform the VPI calculations for state 3, the results are that VPI > 0 only in the following range of the relative value of defense spending versus expected destruction:

$$k_3 f^i_{30} < g / a\ b < k_3 (f^i_{30} + c\ d^k_{max}).$$

The magnitude of this range of relative values is

$$c_3 k d^k_{max} .$$

Next, we note that for our representative numbers (see Section 5.2.3):

$$c_3 k d^k_{max} < 2 k_1 d^k_{max} < 2 k_2 d^k_{max} .$$

Therefore, perfect information has a positive value over a smaller range of the relative value of defense spending versus of expected destruction.

5.5.3 The Effects of Information

Next, we summarize the effects of information about country k's arms procurement and violation decisions on the arms procurement and violation decisions of country i. Since we found that uncertainty did not have a large impact, it is not be surprising that the effects of information are not major. However, several important conclusions are drawn from the value of information analysis using our probabilistic model. In each state, the results of our VPI analysis was a range of g / a b, the relative value of defense spending versus expected destruction, for which the VPI was nonnegative.

First, the value of perfect information is zero for most problem parameters, since for large ranges of relative values, country i's arms procurement and violation decisions do not change, even when the decision-maker has perfect information on country k's arms procurement and arms violation decisions.

Second, for the representative numbers used in our analysis, state 2 had the largest range of relative values with nonnegative VPI and state 3 had the smallest. Therefore, information about the opponent's arms procurement and arms violation decisions has less value in state 3; however, this conclusion depends on the assumed effectiveness of strategic defense.

Third, in our baseline alternatives, with perfect information that country k is violating the arms control agreement country, i never strictly prefers to violate the arms control agreement. However, if country i knows that country k plans to procure, country i is indifferent between procuring and not violating and procuring and violating.

Finally, the effects of information are more significant, when we consider the incentives to procure strategic defense in states 1 and 2. The decision to procure strategic defense and violate dominates the decision to procure and not violate the arms control agreements. Like the baseline states of the world, the value of information is positive only for a small range of g / ab, the relative value of defense spending versus expected destruction; however, this range of values is twice as large with strategic defense compared to without strategic defense.

6. SUMMARY AND CONCLUSION

6.1 Summary of Results

The major results of this dissertation are based on the general research scope and assumptions described in Section 1.2 and the more specific modeling assumptions of Section 5.2. We list the general results of the analysis and then describe the conclusions of our analysis of each state of the world.

General Results

Our analysis of potential attack and crisis stability identified four major issues. First, the major concern with reduced levels of nuclear weapons is that the probability of war may increase, if the destructiveness of war is reduced to "acceptable" levels (see Section 6.4). Second, a critical issue in the alternative states is the credibility of extended deterrence to the NATO allies, without the current large numbers of American nuclear weapons deployed in Europe. Third, since the nuclear weapons levels are lower, survivable forces in state 2 and a survivable nuclear capability in state 3 are more critical than survivable forces in state 1. Finally, the nuclear weapons of third countries, in states 2 and 3, raise an important design issue, not treated in our analysis.

The major results of the arms procurement and control stability analysis are based on the conceptual framework identified in Chapter 2 and the assumptions of the expanded model formulated and analyzed in Chapter 5. Our national security value model uses two pairs of relative values. Our national security value model assigns value b to each unit of country less defense industry value and 1-b to each unit of defense industry value. Our country less defense industry value model assigns value a for each unit of expected destruction and 1-a for each unit of defense spending. Since we model the defense industry value as the defense spending, the critical relative values are $g / a b$, the ratio of the value of defense spending versus expected destruction. (For our modeling assumptions, we can express g as: $g = 2 b - a b - 1$.) The major analyses are plotted in the a-b plane and the incentive to procure is defined as the region in which the decision-maker's relative values result in a procurement decison.

First, the decision-makers' relative values ($g / a b$) are the most important parameters affecting the arms procurement and arms violation decisions. Regardless of the decision-making concept, there was always a wide range of relative values for which the decision-makers prefer to procure.

Second, the model results for nuclear weapons procurement decisions are especially interesting. Procurement of equal controlled amounts of nuclear weapons (e.g. SALT II) is never optimal in states 1 and 2, since it increases each country's potential destruction, costs money, and does not reduce the probability of war. Furthermore, with cooperative decision-making, it is never optimal to procure uncontrolled nuclear weapons in states 1 and 2;

however, in state 3, the decision-maker is indifferent between procuring strategic defense or uncontrolled nuclear weapons, since our model assumes that the existing strategic defense is adequate to prevent nuclear weapons from causing damage.

Third, the results strongly depend on the strategic defense assumption adopted in each state. The incentive to procure strategic defense in states 1 and 2 is greater than the incentive to procure the other defense products and creates an incentive to violate the arms control agreements. Since strategic defense is assumed not to affect the probability of war in state 3, the noncooperative decision-making incentive to procure conventional and uncontrolled nuclear forces is greater than the incentive to procure strategic defense. However, the major results of state 3, and the decision-maker's assessment of the probability of war in state 3, strongly depend on the effectiveness of strategic defense.

Fourth, the decision to procure uncontrolled nuclear weapons versus conventional forces depends on the decision-making concept. For cooperative decision-making, the decision-makers prefer conventional forces, since the expected destruction is less. However, for non-cooperative decision-making, the decision-makers do not consider the effects of their procurement decision on the other country and, therefore, are indifferent between uncontrolled nuclear weapons and conventional forces.

Fifth, the effects of uncertainty are not significant, since uncertainty affects decision-making only in a small range of relative values. Our analysis considered the other country's future arms procurement and violation decisions uncertain. The basic incentive structure does not change, but uncertainty increases the incentives to procure (in state 1 and 2 without strategic defense and state 3) and the incentive to violate the arms control agreements (in state 1 and 2 with strategic defense). Since uncertainty can increase country i's perception of the potential damage should war occur, country i procures weapons to reduce its perceived probability of war.

Sixth, since information has value only if it affects the decision, the value of information, in states 1 and 2 without strategic defense and state 3, is nonzero only for a small range of the relative values of defense spending versus expected destruction. The range of relative values with nonzero value of information doubles in state 1 and 2 with strategic defense versus without strategic defense.

Seventh, the ability to perfectly control the other country's arms procurement decision results in the largest incentive to procure. The optimum decision is to never let the controlled country procure. Then, the controlling country makes its procurement decision based on its relative values, assuming that the controlled country does not procure.

Finally, a properly designed leader/follower approach results in less incentive to procure than collusion. If the follower has the largest defense capability and the best technology, the leader's incentive to procure is reduced by the threat of the follower's response. The follower has more risk under this arms control approach, since it will be difficult for him to catch up if the leader violates the agreement; therefore, the follower should be the country with the most information about the opponent's arms procurement decisions. These arguments suggest that the U.S. should be the follower and the Soviet Union should be the leader. Also, leader/follower arms control agreements might be easier to negotiate than more detailed arms control agreements. Therefore, of the decision-making concepts evaluated in this research, leader/follower offers the most promise for maintaining the weapon levels of any state of the world and offers promise as a transition strategy from the current state of the world to other states with lower weapons levels.

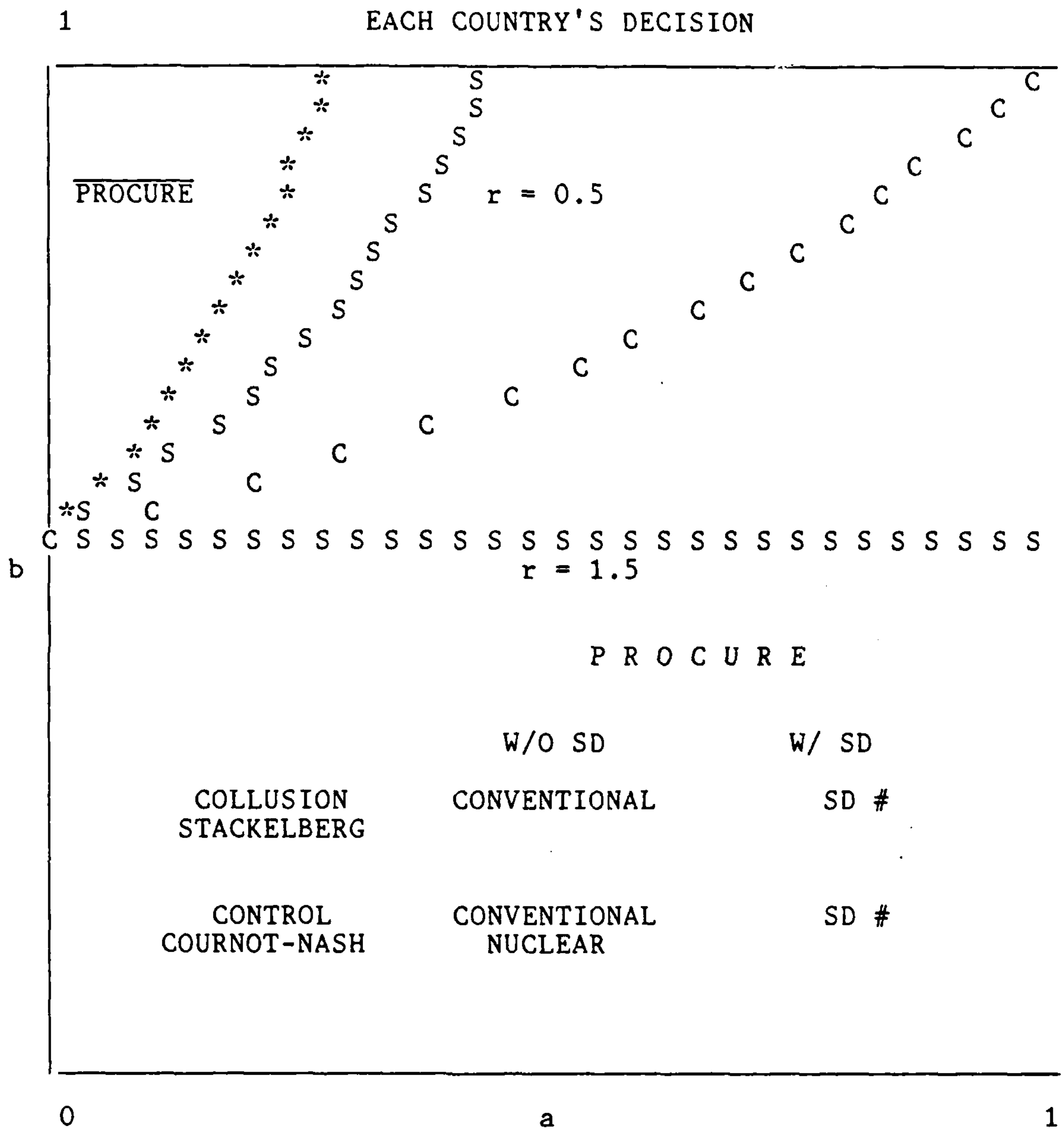
State 1

The large nuclear weapons levels serve two fundamental purposes. First, the high levels reduce the effects of uncertainty about the other country's arms procurement and arms violation decisions. Second, large numbers of nuclear weapons are a constant reminder of the unacceptable destruction that could result from a nuclear war.

For each decision-making concept, Figure 6.1 plots the state 1 procure and do not procure regions and provides a table summarizing the arms procurement and violation

S T A T E   1

$$d^{F}_{MAX} = r\, d^{L}_{MAX}$$



VIOLATION OF THE ARMS CONTROL AGREEMENTS

* = COURNOT-NASH W/ $f^{i}_{S} = 2.5$, CONTROL, STACKELBERG W/ r=0

S = STACKELBERG r=0.5 or 1.5

C = COLLUSION

Figure 6.1

decisions. Without strategic defense, the decision-makers never strictly prefer to violate the arms control agreements. However, with strategic defense, there is an incentive to violate the agreements. State 1 is the most arms procurement stable (See Table 5.1), since it has the largest incentive to procure; this incentive to procure is an attempt to reduce the expected destruction by reducing the probability of war. We found that the high levels of nuclear weapons reduce the effects of uncertainty and, therefore, the value of information.

State 2

We found that the probability of an accidental missile launch was slightly reduced in state 2 compared to state 1. The survivability of the relatively small number of nuclear weapons becomes more critical in state 2 than state 1; however, single warhead systems would significantly reduce the fear of premption in a crisis.

The arms procurement and control stability analysis for state 2 is summarized in Figure 6.2. This figure contains the same type of information as Figure 6.1 for state 1. Compared to state 1, state 2 is less arms procurement stable, but more arms control stable. Compared to state 3, state 2 is more arms procurement stable, but less arms control stable. Uncertainty has the largest effect and, therefore, the effects of information are relatively more important.

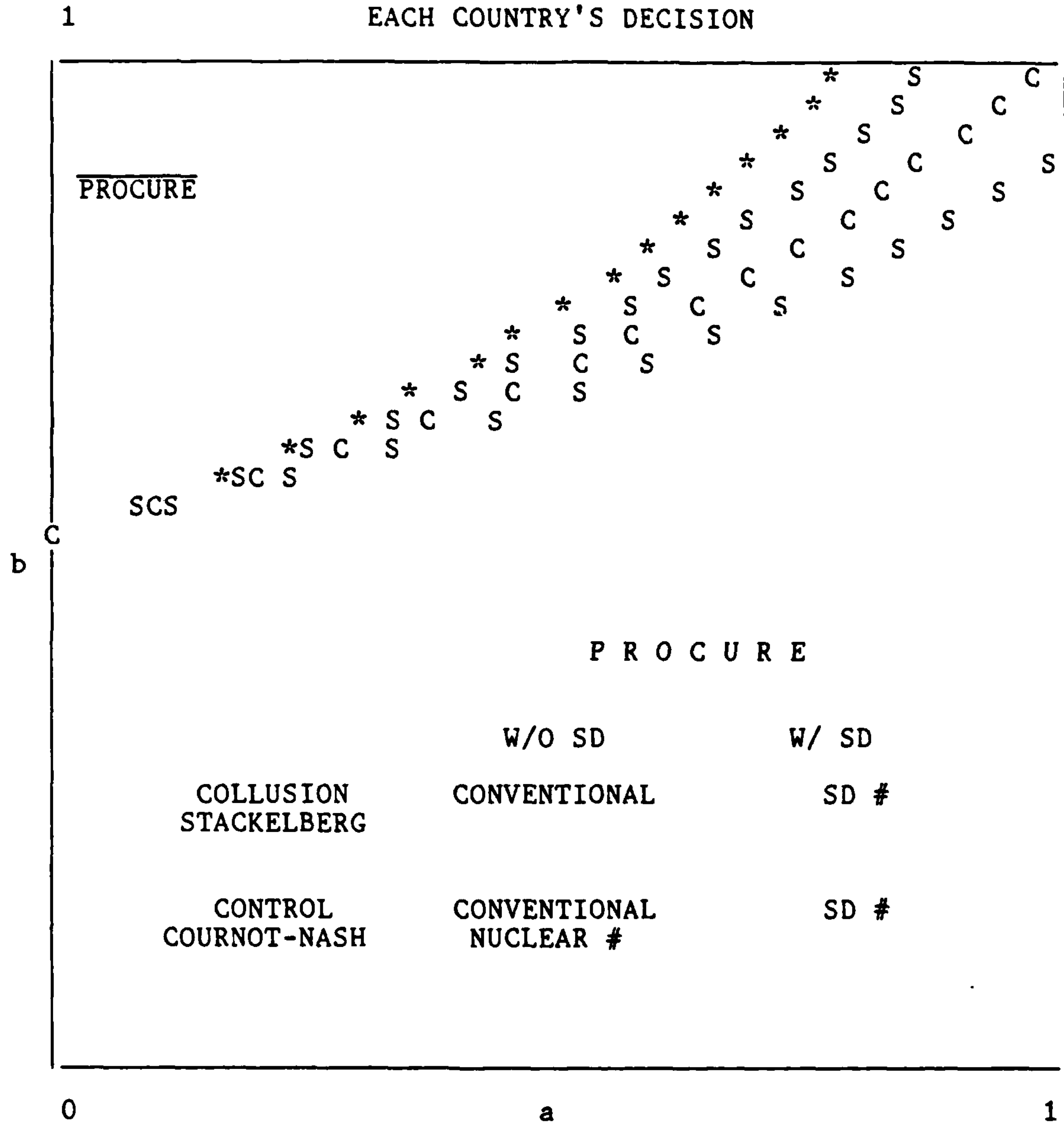
State 3

Since nuclear forces are not on constant alert, the

STATE 2

$$d^{F}_{MAX} = r\, d^{L}_{MAX}$$

EACH COUNTRY'S DECISION



VIOLATION OF THE ARMS CONTROL AGREEMENTS

* = COURNOT-NASH W/ f^{i}_{S} = .25 CONTROL, STACKELBERG W/ r=0

S = STACKELBERG r=0.5 (TOP CURVE) or 1.5 (BOTTOM CURVE)

C = COLLUSION

Figure 6.2

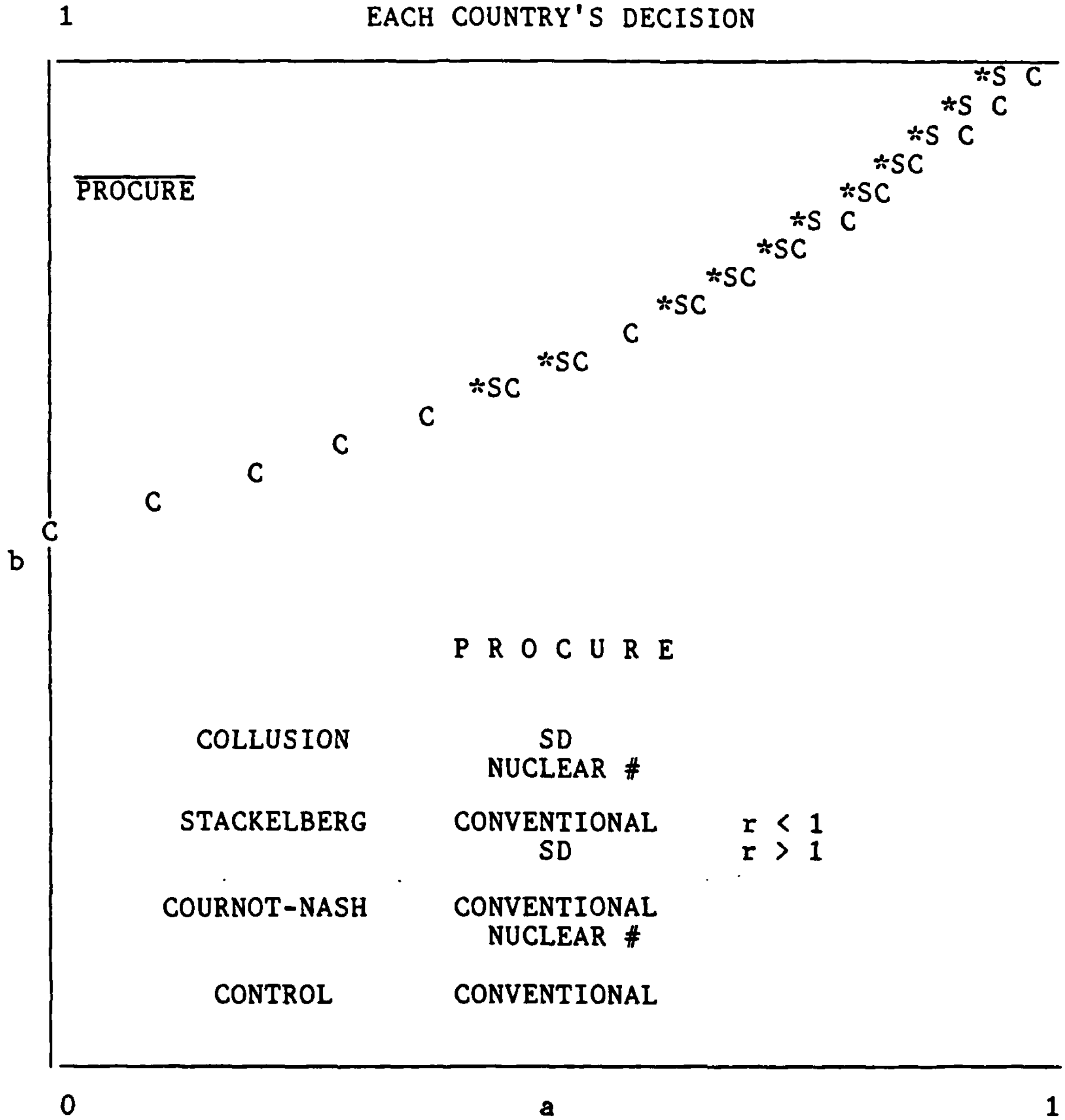
risk of potential attack instability is zero, unless one country violates the agreement. The superpower crisis stability of state 3 depends on the availability of information about the opponent's nuclear weapon's capability.

It is essential that the nuclear capability be secure during the activation phase and, therefore, the survivable nuclear capability requires different characteristics than today's strategic triad. For example, SLBMs would not be a survivable capability, since the submarines would be vulnerable to conventional and nuclear attack during the capability activation phase. Also, small numbers of submarines with unassembled nuclear weapons would be difficult to verify and would provide incentives for antisubmarine warfare. A weapon system that would be secure during the capability activation period is ICBM basing in a mountain.

Figure 6.3 summarizes the results of the arms procurement and control stability analysis for state 3. By comparison with Figures 6.1 and 6.2, state 3 is the least sensitive to the decision-making concept, since the curves almost coincide in Figure 6.3. In state 3, the decision-maker never strictly prefers to violate the arms control agreements. With effective strategic defense, the effects of uncertainty are not significant and, therefore, the range of relative values with positive value of information is small; however, without strategic defense, this state would be less stable than state 2.

S T A T E   3

$$d^{F}_{MAX} = r \, d^{L}_{MAX}$$



VIOLATION OF THE ARMS CONTROL AGREEMENTS

* = COURNOT-NASH W/ f^{i}_{S} = .05 CONTROL, STACKELBERG W/ r=0

S = STACKELBERG r=0.5

C = COLLUSION

Figure 6.3

6.2 Contributions

I believe this dissertation research provides four major research contributions. First, it provides a conceptual framework that captures the fundamental structure of nuclear arms procurement and control decision-making in quantitative terms. Our goal was to describe the fundamental underlying structure in a manner that would allow us to focus on the incentives for arms procurement and arms control agreement violations in the current and alternative states of the world. Our research identifies four major interrelated factors: the superpower international competition, the nuclear security dilemma, technology, and the defense industries. To examine alternatives for large bilateral reductions in nuclear weapons, we assume that the superpowers agree to limit or constrain their international competition. Next, we describe the last three factors in the following conceptual economic framework; two governments (countries) funding two monopolists (defense industries) to provide complementary public goods (weapons), each using essentially the same technology, to two different groups of consumers (citizens).

Second, this research contributes to the knowledge of alternative futures with significantly less nuclear weapons by attempting to design plausible alternative arms procurement and control states. The majority of the literature focuses on the reasons why alternatives with significantly less nuclear weapons are implausible and unstable. The focus of our research was to attempt to design alternatives that would be plausible and stable. The political-military characteristics of our two alternatives are described in Chapter 3.

Third, this research identifies an analytical framework for examining the plausibility and stability of alternative states of the world with large bilateral reductions in nuclear weapons. We focus our analysis on four major decision problems that affect our perception of plausibility and that could result in major instabilities: a potential missile attack, a major superpower crisis, arms procurements that do not violate the agreements, and arms procurements that do violate the arms control agreements. Major superpower crisis stability, which is critical because most analysts believe that war would be more likely with lower levels of nuclear weapons, is the most difficult to analyze, since it is impossible, a priori, to specify all the potential decisions and outcomes. Furthermore, arms procurement incentives are very important and strongly related to the arms violation incentives.

Fourth, our research expands the conceptual framework into a static microeconomic model, which we use to analyze arms procurement and control stability. The model has complex interrelationships and a large number of variables; however, the linear constraints simplify the mathematics without a significant loss in realism. We use existing microeconomic static equilibrim concepts and decision analysis techniques to answer interesting questions about arms procurement and arms violation incentives in the alternative states.

6.3 Model Limitations

The modeling techniques used in this dissertation have important limitations and, therefore, should be used cautiously in drawing policy implications. The conceptual framework of Chapter 2 and the expanded model of Chapter 5 are still gross simplifications of an extremely complex reality. Furthermore, the modeling is based on the general assumptions made in Section 1.2 and the detailed modeling assumptions made in Chapter 5.

The model is extremely difficult, if not impossible, to validate for the current state, much less the alternative states. However, the model does reasonably describe superpower incentives in the current state. For example, the model results in a large incentive to procure weapons in the current state and, as expected, strategic defense is arms procurement and arms control destabilizing in states 1 and 2. Results, such as the above two examples, increase the model's credibility, since the results correspond to our continued procurement of weapons and confirm the strategic defense assessments of most strategic analysts.

6.4 Suggestions for Future Research

We identify four major suggestions for future research. First, researchers concerned with the current high levels of nuclear weapons should focus their efforts on the identification and design of plausible and stable alternative futures. It will continue to be difficult to mobilize public and government support for significant reductions in nuclear weapons, without offering plausible and stable alternatives. Our research highlites the role of strategic defense and the change in the probability of war at reduced levels of nuclear weapons as major research issues. Alternatives which prohibit strategic defense must deal with the incentives to violate the agreement and procure strategic defense. The assessment of the probability of war in alternative states is a critical issue, and especially difficult for alternatives that are significantly different from our current state, e.g., zero-nuclear-weapons deterrence. Both of these important issues require further research.

Second, additional insight into the stability of alternatives with large nuclear weapon reductions can be obtained by further arms procurement and control modeling and analysis. In our modeling, we attempt to capture the complementarity of the public goods (weapons) in our model of each country's assessment of the probability of war. An alternative approach is to model each country's demand function directly. Another area for further analysis is alternative value models. One possible addition is the assignment of value to maintaining the arms control agreements. A second addition is the assignment of direct value to the level of nuclear weapons. Also, researchers could develop and analyze national security utility functions.

Third, additional insight into the stability of the alternative states of the world could be obtained by converting our static model to a dynamic model. The dynamic model could be formulated in continuous or discrete time; however, discrete time would be more realistic, since budget decisions are made annually. The dynamic model might require simplification to allow for closed form solution. The major benefit of a dynamic model would be that it allows us to obtain insight into multiperiod decision-making by using the stability analysis techniques of control theory.

Finally, once the desired objectives are specified, researchers could focus on strategies that could be used to make a transition from the current state to a desired state. A potential first step is the identification of alternative transition strategies. Next, a dynamic model, such as the one discussed above, could be used to analyze the alternative transition strategies.

6.5 Conclusion

Both minimum deterrence and zero-nuclear-weapons deterrence have major plausibility problems. Surprisingly, the two most stable states are the current state and the zero-nuclear-weapons state. The minimum deterrence state was the least preferred by almost all stability criteria. The strategic defense assumption was critical is all states of the world; the good stability results of the zero-nuclear-weapons state result directly from the effectiveness of strategic defense.

In this chapter, we have summarized the major results and limitations of the research. A fundamental perspective focusing our research has been the belief that the incentives for arms procurement and violation decisions must be included when analyzing arms control alternatives. The research has provided improved insight into arms procurement and control decision-making and alternative states of the world with significant reduction in the levels of nuclear weapons.

APPENDIX A - MAPPING WEAPON SYSTEMS INTO DEFENSE PUBLIC GOODS

The purpose of this appendix is to describe the problem of mapping the many types of weapon systems into defense public goods. Let the three defense public goods for country i be the following:

x^i - the amount of offensive nuclear weapons

y^i - the amount of conventional weapons

z^i - the amount of strategic defensive weapons

Next we define the number of each type of weapon, the number of different types of weapons, and the sets of all types of weapons in each category as follows:

q^i_k - country i's quantity of weapon systems of type k

N^i - set of all nuclear weapon systems of country i

n_i - number of different types of nuclear weapon systems

C^i - set of all conventional weapon systems of country i

c_i - number of conventional weapon system types

A^i - set of all strategic defense weapons of country i

a_i - number of different types of strategic defense weapons

In mathematical terms, the problem of mapping country i's weapon systems into the three defense public good categories can stated in terms of the existence of three matrices of functions, f, g, and h, such that, for example, $\underline{f} = (f_{ik})$, i = 1,2 and

$$\text{for all } q_k^i \text{ in } N^i, \quad f_{ik} : w_k^i \rightarrow x^i \quad k=1\ldots n_i$$

$$\text{for all } q_k^i \text{ in } C^i, \quad g_{ik} : w_k^i \rightarrow y^i \quad k=1\ldots c_i$$

$$\text{for all } q_k^i \text{ in } A^i, \quad h_{ik} : w_k^i \rightarrow z^i \quad k=1\ldots a_i$$

For our modeling objectives, the credibility of the f functions is good for ICBMs, SLBMs, and INF. Because of necessary assumptions about the interaction with conventional defenses and offenses, f is less credible for strategic bombers and functions need to be developed for theater and battlefield nuclear weapons. The credibility of the g functions is the lowest since conventional force effectiveness depends on the objectives and the geography. Estes (1983) notes that this is ironic, since we have much more data and experience with conventional forces than with nuclear weapons. However, functions do exist for converting quantitative and qualitative conventional force characteristics into a single variable, for example, Armored Division Equivalents (ADEs) (Posen 1984). The credibility of the strategic defense funtions, h, is probably as good as the f functions.

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